A UNITED STATES
DEPARTMENT OF
COMMERCE
PUBLICATION

BUILDING SCIENCE
SERIES 1

Man and His Shelter

Performance of Buildings Concept and Measurement

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

UNITED STATES DEPARTMENT OF COMMERCE • Maurice H. Stans, *Secretary*
NATIONAL BUREAU OF STANDARDS • Lewis M. Branscomb, *Director*

Performance of Buildings—Concept and Measurement

Proceeding of the 1st Conference in a Series of Conferences on

Man and His Shelter

Held at Gaithersburg, Maryland
September 23–25, 1968

Edited by

W. W. Walton and B. C. Cadoff

Building Research Division
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

Building Science Series 1

Nat. Bur. Stand. (U.S.) Bldg. Sci. Ser. 1, 132 pages (January 1970)
CODEN: BSSNB

Issued 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 (Order by SD Catalog No. C 13.29/2:1), Price $2.75

Abstract

The Conference entitled "Performance of Buildings—Concept and Measurement" was held at the National Bureau of Standards, Gaithersburg, Md. on September 23–25, 1968. This was the first in a planned series of conferences on "Man and His Shelter." The purpose of these conferences is to bring together those people from various disciplines who may contribute to improving the quality of man's shelter. At the present conference, papers were presented by nineteen authors representing government and industry in such diverse disciplines as architecture, engineering, science, urban planning, and standards. These papers emphasize the prime importance of considering user needs in the development of performance criteria, the necessity of test methods to determine whether the desired performance has been achieved, and the development of performance specifications and standards. Application of these ideas to building systems, and to the planning and design of entire communities, is also discussed.

Key words: Building systems; performance of buildings; standards; test methods; urban planning; user needs.

Library of Congress Catalog Card Number 70–600414

Foreword

Since as early as 1905, the National Bureau of Standards has developed test methods, standard practices, and data on the properties of materials used in the construction industry. These data and test methods have been widely incorporated in building standards and codes in use today. If this country is to meet its vast construction needs major changes in standards and codes must be made to accommodate existing technological advances and encourage others anticipated in the future. As with so many other technological problems facing us today, the most fruitful approaches to solutions will be interdisciplinary; physical scientists, behavioral scientists, lawyers, mathematicians, architects, engineers—all have a role to play. It is our intent that the National Bureau of Standards shall in the future, as in the past, serve as an important focus of interest for those concerned with assuring the technical soundness of building standards and codes.

It is in this context that the first of a planned series of conferences on "Man and His Shelter" was held at the Gaithersburg laboratories of the National Bureau of Standards in September 1968. This volume gives the proceedings of that Conference.

Lewis M. Branscomb, *Director*

Preface

These are the proceedings of the Conference on the Performance of Buildings—Concept and Measurement, the first conference in the series. The conference was sponsored by the Building Research Division, Institute for Applied Technology and was held at the National Bureau of Standards, Gaithersburg, Md. in September 1968.

The meeting was attended by approximately 300 scientists, engineers, architects and other professionals in the building industry. The participants exchanged ideas and discussed problems in an atmosphere that encouraged cooperation—so necessary in the fragmented building industry. (The questions and discussions that followed the talks are not included in these proceedings.)

The "Performance Concept" includes a range of ideas from user needs to actual measurement of the performance of materials, components, and building systems. The comments received since the conference, indicate that it was successful in establishing a sharper picture of performance as applied to the building industry.

The banquet provided the highlight of the conference when the Honorable C. R. Smith, Secretary of the U.S. Department of Commerce, introduced the Honorable Robert C. Weaver, Secretary of the U.S. Department of Housing and Urban Development, who spoke eloquently on the problems of furnishing decent shelter for our people.

The editors gratefully acknowledge the cooperation and assistance of the NBS Office of Technical Information and Publications and the secretarial staff of the Building Research Division and the Institute for Applied Technology in conducting the conference and the publication of the proceedings.

W. W. Walton
B. C. Cadoff

Contents

SESSION I. INTRODUCTORY

W. W. Walton, Chairman

WELCOME TO NBS

Lawrence M. Kushner, Director

Institute for Applied Technology
National Bureau of Standards

It is my pleasure to welcome you to the National Bureau of Standards. I bring you greetings from Dr. Astin, our Director, and his wishes for a most successful meeting.

This session on the Performance of Buildings is the first of what we hope will be a series devoted to the broader subject of Man and his Shelter. Man has always sought to improve his shelter by gradually utilizing incremental improvements in technology. Today, however, with the tremendously rapid advances of modern technology and the exponential growth of population, the slow progress of the past is no longer acceptable. It cannot keep pace with the rapid changes of today's needs.

Buildings or structures represent over half of the existing tangible wealth of this country. Aside from the long-term economic significance, the annual building production is in the range of $100 billion, with an effect in every village, town, and city in the country. In addition to this economic significance, the turbulent political and social forces, so evidently active, are clear indications that we can no longer be content with previous rates of progress. We must attack the problem directly.

To provide shelter for man, at work, at home, and at play, that is commensurate with our present scientific and technical ability is a challenge that can be solved only by a full interdisciplinary attack. There must be a dialogue (and we hope this is the beginning of such) among the professionals concerned with the building process. Engineers must solve problems of structures, heating, cooling, air flow, and plumbing; chemists must create new materials and determine the interaction of materials with one another and their environment; psychologists must investigate the effect on man of space and all of its shapes, light and all of its colors, and sound and all of its characteristics; mathematicians must adapt the computer to the needs of the building industry; economists must control costs, sociologists must assure that we are constructing a community, not just a building, and, of course, architects must blend all these approaches together to create a shelter for man which will truly satisfy his needs.

The purpose of these conferences will be to bring together all these people to talk, to exchange ideas and knowledge, and to inspire each other to work together productively. Because we are faced with a need for such rapid change, there will be no opportunity for feedback from years of experience with new innovations—no time to contemplate. This imposes a greater need for research than ever before; we must create a broad base of knowledge, upon which we can draw for the solution of problems.

The National Bureau of Standards has long had an active interest in building research and technology. This interest stems directly from the responsibilities of the Bureau for leadership in the Nation's measurement activities. As early as 1905, the Bureau had a 100-thousand-pound testing machine which was busy measuring the strength of various structural materials, such as steel, and concrete, and so forth. Later on, the Bureau undertook a program with the National Fire Protection Association and the Underwriters' Laboratory, from which there flowed a considerable amount of data on the fire resistance of materials; these data were subsequently incorporated in fire and electrical codes throughout the country. During the 1920's, under the administration of then Secretary of Commerce, Herbert Hoover, we were concerned with a Better Homes Program. During the Depression of the 1930's, our attention was directed toward low-cost housing; during World War II, to the conservation of scarce building materials. After the War, for fifteen years or so, there was a return to programs which stressed the properties of the various kinds of building materials. But today, the Bureau's interest in building technology is a very broad one. We are concerned, not only with problems related to materials, but rather with the function and performance of buildings as they satisfy the user.

There are two aspects to the performance of buildings. The first concerns the needs of the

user—is the temperature too high, too low, too variable; are there noises in the building that affect his productivity or comfort; is the light too glary or too gloomy; does the floor plan expedite his work or is it consistent with the family pattern of living; is the floor too hard or too soft. The second performance aspect deals with buildings' physical functioning—how safe is the building; how well does the thermostat control the temperature of the space; how loud are the noises in the building and how are they transmitted; how efficient is the lighting system and how much heat does it generate; how much energy is required to walk or push a cart over a soft floor; do the walls leak air, water, or heat; what is the life expectancy of the paint on the wall. These two aspects are closely interrelated, but the methods of measurement are dissimilar.

The primary concern of this conference will be with the second aspect. The problems relating to the measurement of performance of buildings will be discussed and solutions presented. We hope that the free exchange of ideas at this conference will help to eliminate much of the confusion surrounding the term, "performance concept."

MAN AND HIS SHELTER – A DIALOGUE BETWEEN SCIENCE AND TECHNOLOGY

J. P. Eberhard

School of Architecture
State University of New York
Buffalo, New York 14214

I welcome an opportunity to be back here. I appreciate the good efforts of Dr. Wright, Dr. Walton, and Dr. Kushner in seeing that I could get back. I think and I hope it proves that old bureaucrats don't die, don't fade away, but just come back in orbit once in a while to the place where they once shone.

I want to talk about two things with you in this keynote address: The first is why these conferences are important to you, to the National Bureau of Standards, and to the nation. The second is the challenge that I believe is posed to all of us who are concerned with performance standards by the concept: Man and his Shelter.

The conference actually began with a research contract we gave to Mr. Allen, who, appropriately will be the closing speaker in this conference. In his report he explored on our behalf the kinds of things we ought to be doing in the future in the Building Research Division in the Institute for Applied Technology to make it more relevant to the coming changes in the building industry.

One of his recommendations was that there needed to be more conscious and direct liaison with the building industries, and particularly with those professionals who, in a sense, were on the front lines of the building industry, making the day to day decisions. It was from this advice that, through a series of recommendations, we organized a new section in the Building Research Division, for which Dr. Walton is responsible. And, this is the first conference that grew out of these recommendations.

The quote that I would like to read to you first has to do with why I feel it is important that we form this link between the National Bureau of Standards and people who are active in the building industries. It is a quotation from one of my favorite books, Alexis de Tocqueville's Democracy in America. He tells at one point in his book, about a problem that he observed as a result of America's deep involvement with practical affairs. He says,

> "When the Europeans first arrived in China, three hundred years ago, they found that almost all the arts had reached a certain degree of perfection there, and they were surprised that a people which had attained this point should not have gone beyond it. At a later point, they discovered traces of some higher branches of science that had been lost. The nation was absorbed in productive industry, the greater part of its scientific processes had been preserved, but science itself no longer existed there. This served to explain the strange immobility in which they found the minds of this people. The Chinese, in following the track of their forefathers, had forgotten the reasons by which the latter had been guided. They still used the formula without asking for its meaning. They retained the instrument, but they no longer possessed the art of altering or renewing it. The Chinese, then, had lost the power of change. For them, improvement was impossible. They were compelled at all points to imitate their predecessors, lest they should stray into utter darkness by deviating for an instant from the path already laid down for them. The source of human knowledge was all but dry, and, though the stream still ran on, it could neither swell its waters, nor alter its course."

It seems to me in many ways that the building industries in the United States face this problem that existed in China four hundred fifty years ago. We differ in one major respect, or course, and that is that exploration of science has not stopped. My concern is that the science that *is* being explored is essentially irrelevant to our purposes, that the scientific effort that's going on in this nation, that goes on within the building industries is not well related to man and his shelter; is not well related to those main problems in our society which we will have to solve and which will require the redirection of our efforts. It seems to me that those who make the day to day decisions – that's who I'm speaking of principally here – from the front lines of the building industries have by and large a strange immobility of mind, and that by following in the track of their forefathers, they tend to use the formula

without asking for its meaning, and consequently, tend to no longer possess the art of altering or renewing it.

The National Bureau of Standards, which I discovered only five years ago, when I came to Washington, and which I hope many of you will discover for the first time today if you're not aware of it, is a real fountain of knowledge with respect to the scientific bases of decisions made in the building industry. But I think it is bubbling just beneath the surface of consciousness in the United States. For more than sixty years, as Dr. Kushner told you a few moments ago, amazing progress has been made here in advancing the concepts and techniques of physical measurement.

Let me tell you a little bit about physical measurement and the kinds of things that are going on here and have gone on here for sixty years, on the presumption that this will be educational to you. I think it will also be illustrative of something else I want to say in a few minutes. Do you know, for instance, that all physical measurement is based on six fundamental measurement concepts: length, mass, time, temperature, ampere—the measurement of the flow of electricity, and what is now known as candela—the measurement of the flow of light? From these six fundamental phenomena, all other physical measurement are derived.

I want to talk about one of those concepts. I want to talk about the concept of length and to give you some idea of why there are still more than three thousand people employed in a National Bureau of Standards that's responsible for fundamental measurement. I'm indebted for this story—sort of second-hand—to Dr. Alvin McNish. If I were to put five dots on the blackboard and ask the question: "How far apart are these dots?," I have asked about the concept that has to do with length. In about 1901, when the National Bureau of Standards was first formed, the sophistication required to answer that question was not unlike having to simply agree, you and I, about what we meant by a unit of length. We could have elected in 1901, by the way, to pick up the Metric System, and we wouldn't have some of the problems we have today; but we didn't. We decided to use things that we borrowed from our English friends called yards and feet and inches, and what we needed then in order to answer the question, was an agreement that, if we had a straight edge, and we divided it into sections and subdivided those sections into subsections, that we could agree that this was a unit of length. And, therefore, we could say that these dots were approximately four inches apart. Well, that would serve us fine, let's say, until about World War I, when someone would say we would have to be more accurate because our instruments have become more sophisticated, our needs for fit are more precise. Just telling me, "Four inches" isn't precise enough. So, what we do is develop a much more finely calibrated instrument for measurement, and we'll find that the result is 0.32967 foot, or within a few decimal places of being four inches. This would work for a decade or so, when someone would say, "You know, let's be more definite now, about our measurement of how far it is between these dots. And, if I look at one of these dots under a microscope, I discover that its edge has many undulations. Now, when you say how far is it between those dots, what do you mean—from this point or this point or that point? Be more definite, my friend." Well, it's obvious that we're going to have to adopt again some arbitrary decision about what we are going to mean by "edge." And, the most logical would probably be that we would decide that we would use the mean arithmetical average of those undulations of the edge of the dot as perceived under a ten power microscope.

One of the things that happens in this shift is that we are now, no longer measuring the actual phenomena which we witness, but what we are measuring is something we've agreed on as a convention; namely, the arithmetical average from this point to the next point. And, we can, with instruments that become more accurate, express that distance more accurately. That will serve us for a number of years, and then, let's say, roughly about the time of World War II, someone will say again, "Let's be more definite, because, if I look at this dot on this blackboard under a powerful microscope, what I see is, not chalk and blackboard, what I see is molecules. And, those molecules no longer possess the property of color; therefore, I don't have white and black as contrast. Also, I have a much more differentiated surface than what I saw at only ten magnifications. And so, what I'm saying now is, how far is it from one molecule in this dot to the molecule in the next dot? And, if what I want to do is measure that in some way, I'm not going to be able to do it with a straight-edge ruler, because, if I look at that, I'll see molecules there also." So, now, what we may need to adopt is a convention that has to do with the spectrum of light. And, we would say that there are so many wave lengths of light

between a molecule at this position and a molecule in that position.

That would serve us, roughly until the time of Sputnik, when someone else would say, "Just a moment, let's be more definite again by what we mean, because, if we look at this dot, now under an even more powerful microscope, what we see is, not molecules, but electrons, protons, and neutrons, and, in fact, they are in motion." We now have another shift in our concept. Length now depends, not only on the concept of linearity; we have to introduce the concept of time, since electrons are not in a fixed position. Their positions are only capable of being predicted by the laws of probability. We're going to bring time into our definition and indicate how far apart an electron in this position is from an electron in that position at what point in time.

Well, to some of you—to some of us, before I came here—that may sound like sort of crossing the t's and dotting the i's ad infinitum. But, it's relatively clear that that kind of accuracy and precision in physical measurement has been necessary for the kinds of technological stunts in which we've been involved. For instance, at the time that Sputnik was put up, our ability to measure time accurately was such that the closest we could have expected to come with a moon shot, if we had been capable of launching it at the time, was ten thousand miles. When we compare that to the moon orbit that the Russians accomplished within the last few days, it's clear that that kind of achievement would not have been possible without a vast increase in the accuracy as to what it was we meant by time, and length in order to calculate those kinds of trajectories.

So, I think it's important that you know what's going on here, generally, but it's particularly useful that you should know what's going on here in the Building Research Division. While all of this work is not as fundamental as the work on length that I talked about, it is fundamental in the sense that it underlies the measurement phenomena which most of you deal with every day and which in dealing with every day, you've come to accept as a convention. Even though its original base was arbitrary, we no longer question the arbitrariness of the original decision that was made about how we were going to make these measurements. It's clear that in some areas, we're hung up on the arbitrariness. The easiest one, of course, is "two by fours, sixteen inches on center." Hardly anyone wants to stick to that old paradigm anymore—including the people who are in the business of producing and distributing lumber. No one seems to know exactly how we ever got sixteen inches on center into our technology. I've heard interesting stories from Ezra Ehrenkrantz about its being the distance that was arrived at, because cheap lath was needed in England about two centuries ago. Firewood had been cut sixteen inches long, because the back of fireplaces were two bricks wide, and two standard nine inch bricks made fireplaces eighteen inches wide. Everybody had an eighteen-inch-wide fireplace, so that the kindling wood manufacturers made the wood sixteen inches long to fit into the fireplaces. Kindling wood was a cheap source of lumber, so they chopped it up into lathing, and then they had to put the upright sixteen inches on center. For that, we're now bound into modular concepts ad infinitum, multiples of sixteen inches. There's nothing very sacred about sixteen inches I could pick out ten meters, or centimeters, or any other unit, and if everybody in this room, and all their companies, and all the industries in the United States that made building products wanted to accept it, we could use that. The problem is getting a convention that is rational.

And, that's the other reason I think that you should be here. You should know what's going on here, but, just as important, the people who are working here need to know what's going on out where you are—and, particularly again, those of you who represent what I've called now the front line, the professionals who are making the day-to-day building decisions. When I first came here the Building Research Division was involved in some work which was of questionable relevancy with respect to the urgent needs of the building industries and the clients of the building industries.

Let me cite three examples:

1. Mr. Robinson is responsible for a section in which fundamental work is going on in the measurement of heat transfer properties of materials. He has a very bright man working there, and that young man recently worked for a year on the heat transfer properties of soils at temperatures up to two thousand degrees Kelvin. We don't run into that problem very often in the building industry. In this case, the Space Program did, and that's where the money came from. One spin-off was that the method developed for this work is directly applicable at the lower temperatures of interest to the building in-

dustry, as in problems related to fires.

2. There was another man working on the hydration rate of cement. This work was related to the basic mission of the Bureau on materials measurement methodology and characterization of materials. It should not have been continued in the Institute for Applied Technology. There are more urgent needs in building research, so the project was terminated.
3. And then, there's a project that is being published now, and therefore, will soon be coming to an end, on the presence of trace elements in concrete. It's the dominance of the building materials properties which the Building Research Division had not been able to shake, and which most of you don't want to shake—that is, most of you in this audience. I think one of the reasons why this audience consists of so many people in the building materials business is because of this affinity between the nature of the scientific work that's been going on here on the properties of materials and the materials production people in the building industry.

Any program that's rooted as this program is in basic physical science seems to me to need to reach out its branches and twigs into the fresh air and the sunshine of a changing world. And, that's what I had hoped and still hope these conferences can help to do. The concept of standards, as a means of measuring the performance of an object or a system, has historically lagged the scientific and technological developments of this society. Until the measurement need becomes publicly visible, and until institutional means are developed for arriving at acceptable standards, there can be no nationally recognized set of statements that can be used for standards.

You heard Dr. Kushner say before that, early in this country's history, the need to develop uniform weights and measures helped to create an Office of Weights and Measures, which was established in the Treasury as early as 1830. This organization, later known as the National Bureau of Standards, has continued to function as an institution, with primary responsibility for measurement based on the phenomena recognized by the physical sciences. We are now moving into a period in our national development—accompanied by fleeting insights into the social sciences—when we need to develop new concepts of standardization measurement based on man as the user of objects and systems, as well as man as the observer of the properties of such things.

The measurement system that I talked about before—and its need for accuracy and precision—had to do with man as the observer, man observing a phenomenon called length. We now begin to see through a glass darkly, that the artifacts which a society produces, from guns to cities, do have an impact on man, physiologically, psychologically, and sociologically, and that, in fact, these impacts are both positive and negative. But, our ignorance is enormous. We have little idea of how to measure whether or not one city is better than another, or whether new transportation systems will add to the quality of our lives. The need is now publicly visible. The next question is what form the institutions might take to generate the needed standards.

This brings me to the second part of my talk. I want to talk now about the phenomena in which such institutional mechanisms would be involved if we're going to bring man from a point of perspective in which he is the observer of things that are happening in the physical world to where he, himself, is engaged, either as man in relationship to objects, like buildings, or man with relationships to other men in the society. And, the quotation with which I'd like to begin this section is from Louis Mumford's book, Techniques and Civilization. First I want to read what I consider to be a very interesting biographical note in this Introduction. He's talking about where he gained his experience and background. He says:

> "A few years later, I served as a laboratory helper in the cement testing laboratory of the U.S. Bureau of Standards, then at Pittsburgh, and was immersed in that classic paleotechnic environment."

Probably Louis Mumford would still be a Bureau employee if this conference had been held earlier!

The quotation from his book is:

> "The physical sciences, when they began to emerge, rested fundamentally upon a few simple principles: First, the elimination of quality and the reduction of the complex to the simple, by paying attention only to those aspects of events which could be weighed, measured, or counted, and under the particular kind of space-time sequence that could be controlled and repeated, or, as in astronomy,

whose repetitions could be predicted. Second, concentration upon the outer world and the elimination or neutralization of the observer, as respects the data with which he works. Third, isolation, limitation of the field, specialization of interests and subdivision of labor. In short, what the physical sciences call the world is not the total object of common human experience; it is just those aspects of this experience that lend themselves to accurate, factual observation, and to generalized statements. So that, for example; an ounce of pure water in the laboratory is supposed to have the same properties as a hundred cubic feet of equally pure water in a cistern, and the environment of the object is not supposed to affect its behavior."

We can measure quite precisely, if not always very accurately, phenomena that have to do with the heat transfer properties of building materials. We can measure their structural strength. We can measure whether or not heating and air conditioning equipment is producing the desired number of B.T.U.'s. We can measure whether or not a light fixture is producing enough candela to meet the standard that we decided we wanted for illumination. We can measure whether or not the moisture penetration of particular materials meets our standards and requirements. But, these measurements are based on the kind of phenomenology that I talked about before. They all began as arbitrary decisions, but these arbitrary decisions have been reinforced by practice and by convention and by usage, and it has been possible for any man to reproduce them, as long as he understood the science which underlay the principles that were involved in these measurements.

But, ladies and gentlemen, that's not where our problems lie. The Negro child in Arlington, or my children in a forty-year-old school, who are going to be very cold this winter, when the heating system doesn't work and the windows leak; the young couple who've just been married and built a new home, and find that their floors heave because they haven't been properly laid down; the city that can't get a building built because the building inspector and the trade unions won't permit that kind of construction to occur. Their problems are of two kinds and both are people problems—(1) the relationship of man to man and (2) how man organizes his systems and his politics. That's something which concerns us in this room but lies outside our perspective. They involve man and the objects which he makes. They involve man and the things of his life. They involve the shelter that he creates, in order that he can do the things that he does when he lives that private part of his life in a place we call a home, or when he worships, or when he works, or when he goes to a conference like this. And, we don't understand very well how man relates to these kinds of objects in our society. What we have as a body of wisdom, is really a tradition that's been passed on from generation to generation by people like architects and engineers, that's essentially based on intuition. It's not very systematic; it's not very rigorous; it's not very possible for one generation to benefit from the mistakes of the previous generation. I'd like to cite a very simple example of this: Feedback does not occur, because, if it did occur, after five thousand years of building buildings, you would think we could build buildings that didn't leak. If the Space Program had anywhere near the kind of technological, scientific deficiency feedback that we have in our industry, it obviously wouldn't be where it is to day. Do you remember, about a year and a half ago, when one of the blast-offs was stopped at some point like, "seventy minus zero and counting" (just the fact that almost all of us know those words is some indication of how phenomenally they've been able to take over our culture). When it stopped at that point, there was a problem. If you can conceive of the hundreds of millions of possible problems a huge rocket like that could have at that point in time, and to realize that within a few hours, they were able to pinpoint that it was a small capsule, about the size of the end of my finger, which was not in the orifice when it was supposed to be, you realize how well-organized, how systematic, how rigorous the feedback methodology is of controlling those huge birds. There isn't any reason—there isn't any technological reason—why we have to have a mess in our shelter industry. It's a question of our aspirations; it's a question of our wanting to be involved; it's a question of where we place our bets. And, I'd like to believe—because I'm an optimist I guess, and one of the reasons I'm going to go try to organize a school for young people is that I'm an optimist—that we're ready, we're really ready in this country, at this point in history, to do something concrete and definite and systematic about improving the methodological processes, the technological basis for the kinds of achievements that we could produce in this country by the end of this century.

I think we're going to do it, almost in spite of who's elected President in January. And, when we do that, when we get ready, we're going to have to make a commitment, you and I and the National Bureau of Standards, and particularly those young people who are coming along behind us, who are now just beginning to enter their professional careers in places like universities. And, that commitment is going to have to be one to dare, to dare to break with the paradigms of the past, to dare to be prepared to make the kinds of huge investments that are going to be necessary to provide the body of knowledge which for sixty years we have neglected to develop in this country.

Do you realize that those inventions on which the major structures in our urban environment depend, namely, the elevator (which made it possible to go more than three floors up or five floors up if you cared to walk that far), refrigeration (which made it possible to store food sixty floors up in the air instead of having to go to the shop every day), electricity, plumbing (which eliminated the need to be attached to the ground for the outhouse), the automobile, the subway—were all invented in the twelve years between 1880 and 1892—seventy years ago! Do you know where we would turn in *this* society for new ideas?

The American Institute of Architects, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the National Fire Prevention Association, the American Society of Testing and Materials—you name the professional organizations; they were formed ten years either side of the twelve year period of invention. What about our universities, where the young people are coming from? Every engineering school of any size and every architectural school, except for the few that have just been started, like mine, was founded five or ten years either side of those years of invention. I don't think it's an accident at all that we've perpetuated those inventions. We're hooked on plumbing; we're hooked on electric lights and steel skyscrapers and elevators because we have all the institutional paraphernalia, the building codes, the professional societies, the text books, the college courses to reinforce those inventions. We're going to break with those techniques soon and, when we do, what are you going to do? Are you prepared to adapt to that new world? That's why I say it's a commitment for all of us; it's not going to be an easy adaptation. We're not going to be able to parcel out a few paltry million dollars from our Federal Treasury for research and assume we're going to change the world. We're not going to be able to start an architectural school in Buffalo that produces a new generation of architects and assume we're going to change the world. We're not going to get a major corporation to decide they're going to go into the city-building business and change the world. We're going to have to make vast investments in intellectual efforts and in research efforts, and it's not going to be easy, it's not going to be smooth, and it's not going to be comfortable. But, I think it's imperative. I think it's imperative that you be here, close to the National Bureau of Standards, so that you can draw on these well-springs of knowledge that are not very well known generally in the building industry, and so that they can draw on your well-springs of understanding, the kinds of problems that you face from day to day, the new aspirations that you have for the directions that you're going, so they can make their programs relevant to your purposes.

I'd like to close with another quotation from Mr. Mumford which, I think, underscores what I'm trying to say. He says:

> "No society can escape the fact of change or evade the duty of selective accumulation. Unfortunately, change and accumulation work in both directions. Energies may be dissipated; institutions may decay; and society may pile up evils and burdens, as well as goods and benefits. To assume that a later point of development necessarily brings a higher kind of society, is merely to confuse the neutral quality of complexity or maturity with improvement. To assume that a later point in time necessarily carries a greater accumulation of values is to forget the recurrent facts of barbarism and degradation."

Let's don't let that happen.

MEASUREMENT – KEY TO PERFORMANCE

James R. Wright

Chief, Building Research Division
Institute for Applied Technology
National Bureau of Standards

Introduction

This paper, in effect, could be viewed as the counterpart to the final event on the conference program, which is Mr. William Allen's Summary and Discussion. I say this because it is my aim to provide you with background material that is germane to every talk involving the performance concept, whether it be theoretical or experimental, a laboratory or field application, a talk given in this conference or any other that deals with performance. This statement can be made with a high degree of confidence, since implementation of the performance concept cannot move beyond narrative expression without evaluative techniques; namely, measurement.

My presentation will cover three closely related topics:

1. The National Measurement System,
2. The Performance Concept, and
3. Evaluative Techniques for Both Subjective and Objective Measurement.

I do not plan to tie these separate topics together tightly—that would require too much time and the use of examples that subsequent speakers will provide. Sufficient examples of measurement will be provided, however, to clarify or illustrate key concepts and definitions.

The National Measurement System

Measurement is not only the key to implementation of the performance concept in building, it is, in our present-day, technologically-based society, the key to our daily living. When we glance at the clock, buy a pound of butter, check the car mileage, or listen to radio reports on the temperature of the weather, we resort to an obviously simple use of the four basic measurement quantities; time, mass, length, and temperature. Not as easily recognized is the relationship of these four quantities to the thousands of items which are mass produced for the marketplace. Nor is it commonly realized that the myriad technological wonders of the day are all possible only because there is a complex system of measurements based on these four quantities.

In our post-industrial world, where technology is ever more complicated, we need more and more accurate measurements, and we need them for products, devices, processes and systems which, to be handled adequately, require more advanced techniques and test methodologies than are now available. This is not to downgrade the existing complex measurement system which has evolved with the growth and industrialization of our country. In fact, it is only recently that the concept of a National Measurement System (NMS) has been given formal recognition through the efforts of Dr. Robert D. Huntoon of the National Bureau of Standards [1]. The System has as its main function to provide the basis in the USA for a complete, consistent system for physical measurement.

The NMS is one of a number of important social systems that form the environment in which we function. Others more widely recognized include communication, transportation, education, medical, and legal, to name but a few. The size and scope of the National Measurement System is tremendous. By Huntoon's estimates, there are roughly 20 billion measurements made each day. Based on 1965 data, industries that account for two-thirds of the gross national product annually invest about $14 billion of operating expenditures and 1.3 million man-years in measurement activities. The nation has about $25 billion invested in instruments for measuring, and this investment is increasing at a rate of $4.5 billion per year. Another $20 billion is invested in completed data on properties of matter and materials, and this is being increased at an annual rate of $3 billion. More than 90% of the cost of this total measurement effort is paid for through charges to the user in the market; the Federal Government, as a consumer, bears its share of the cost. But over and above this, the Government contributes to the system by providing a central facility, the National Bureau of Standards, as a resource for

332-247 O - 69 - 2

developing the measurement techniques and standards required for the maintenance or development of the system.

The NMS is built on the principle that "things equal to the same thing are equal to each other." The system is an hierarchical arrangement, whose compatibility is achieved by comparisons at increasing levels of accuracy until, for any measurement quantity, all measurements are referred to a common tie point or standard. The entire structure is anchored on the four basic quantities; mass, length, time, and temperature. By linking the units for all other physical quantities to the units of the four basic quantities, the system is made coherent through the definitions and equations of physics. Looking at it in another way, the primary and derived physical quantities form a set of about 50 measurement quantities which is the core of the System, and from which all other physical measurements of science, industry, and commerce are developed. Derived measurements are, for example, pressure, humidity, acceleration, and volume.

Turning outward from the basic core, we find another set of measurements developed in response to the national need for a readily accessible body of reliable and consistent data on the properties of materials. This part of the system includes evaluated data compilations, reference materials, such as pure chemical samples, critical reviews of quantitative knowledge for specialized areas, computations of useful functions derived from standard reference data, etc. Such information can be used over and over and reduces the duplication of measurements required in the daily operation of our society.

Moving even further from the basic measurements core, we come to the area of technological or so-called "engineering" measurements and standards. These include product or commodity standards, standards of practice, and standard test methods. It is this part of the NMS which contributes most to the building and construction industries.

It should be clearly recognized that technological measurements and standards are at the interface between science and its application to the needs of our society. They are an extension of good measurement, so well defined in the sciences, into the engineering fields and complexes of today's society. In contrast to the relatively few standards in the basic quantities core (four) and derived physical quantities level of the NMS hierarchy (fifty), there are in excess of 13,000 nationally recognized technological standards, and these are predicated upon a user/producer consensus as to what are the important characteristics of the products, processes, or services concerned. Despite the apparent lack of a logical base tying these standards together, the expression of user needs and the description of products, processes or services offered to meet these needs, are measurement functions. As part of the NMS hierarchical structure they are linked through the process of the system to the basic measurement quantities, and thence to the logic of physics.

This, then, is a brief description of the conceptual structure of the National Measurement System—a skeletal framework of basic measurement quantities tied together by the laws of physics—a large body of measurement data which describes our physical world—and a constantly changing multitude of technological measurements and standards which bring order and quantification to man's utilization of his technical skills. What has been omitted in this brief description is the operation of the substructures within the system; the instrument, the data, and the techniques networks which Huntoon elaborated in the work already cited [1].

The National Measurement System concept by spelling out the relationships among the many and varied kinds of measurements carried on throughout the country, opens the way to improved efficiency of the total measurement effort. It lends help in defining what our measurement problems are. And in their solution, it offers a rationale for the choice of the most appropriate methods or techniques. Huntoon has noted that there is a definite trend toward "self-calibration." He predicts that increasingly industrial laboratories will carry out their own calibrations with materials, data, or transportable standards supplied by the National Bureau of Standards serving as the country's central measurement laboratory. The national development of such practices is only possible if they are generated in the context of the System's relationships.

In examining the NMS hierarchy it is quickly evident that the technological measurements and standards-level directly impinges upon our economic growth. Society has accepted the use of technical standards or specifications that embody user consensus of which factors are important and what quantitative levels must be achieved for these factors if a product is to be acceptable in the market. Standards based on evaluation of design

characteristics are essential for uniformity of products, interchangeability of parts, and mass-production techniques. However, such design standards are sometimes inappropriate for complex item evaluations. As the technical sophistication of articles of commerce increases, it becomes more and more difficult to define those characteristics which best describe or measure the performance of such items.

Standards which too rigidly specify how a product shall meet a user's need can inhibit economic growth by closing the way to the development and introduction of new products or services. If standards are to stimulate innovation, they must not rigidly specify the end product design, but rather stress the performance expected in answer to the needs of the user. Thus will producers be encouraged to seek answers which will meet the performance required by any means which will do the job. The use of performance requirements as the basis for standards development introduces man into the measurement process; it provides a crosswalk from the subjective consensus technique for determining what acceptability factors are important to an objective test methodology for measuring these factors.

The Performance Concept

Recently a great many terms have come to be used in discussion of the performance approach to buildings and to the process of building. To stabilize the situation somewhat, we have in the Institute for Applied Technology developed a definition for the performance concept and a set of five terms leading from a performance requirement, based on user needs, to a performance-type building code. The next part of my talk will deal with our concept of performance, the definition of terms employed, and examples that illustrate the use of these terms. My examples will be limited in number and very elementary, but the talks you will hear later from Institute for Applied Technology personnel will provide suitable examples in much more detail, all related to some aspect of building.

The *performance concept* provides a framework within which it is possible to state the desired attributes of a material, component or system in order to fulfill the requirements of the intended user without regard to the specific means to be employed in achieving the results [2]. This is true for any product or system produced for use by humans from shelter to weapons.

The performance concept centers on the idea that products, devices, systems or services can be described and their performance can be measured in terms of user's requirements without regard to their physical characteristics, design, or the method of their creation. The key to the development of performance standards is the identification of significant criteria which characterize the performance expected and the subsequent generation of methodologies for measuring how products, processes, or systems meet these criteria.

There are many ways to describe a solution for a problem. The use of a "hard specification" is one way. The materials specification for an electric razor is an example of a hard specification. Such a specification, in terms of engineering drawings, assembly, instructions, materials listing and the like, identifies a means for cutting off whiskers. But a fundamental question which should be raised is whether this is the best way to meet the basic need. The basic requirement for many men in our society is to maintain their faces free of hair. Whether they cut the hair off daily, pull out facial hair, or selectively destroy the hair-producing cells should be a matter of choice. Obviously, the alternative ways of meeting this basic requirement to maintain the face free of hair are considerably greater if we do not define the requirement narrowly or: as one for cutting the hair off the face.

A "hard" specification describes a solution in terms of its physical characteristics (means characteristics). The performance approach describes the needed solution by identifying the problem-solving characteristics it must have (problem characteristics).

The concept of a performance requirement is basic to the performance approach. In the case of the problem of men's beards, the performance requirement might be stated as follows: Custom in the United States dictates that men keep facial hair in a tidy way. The most generally accepted method is to keep facial hair from becoming long enough to be visible and there is, therefore, a current requirement for means of controlling the presence of facial hair. A *Performance Requirement* is a qualitative statement describing a problem for which a solution is sought. Ordinarily, a Performance Requirement will include identification of:

What—the nature of the problem.
Who has the problem.

Why the problem exists.
Where the problem exists.
When the problem exists.

In the furtherance of our understanding of the various facets of the performance concept, let us use as an illustration an aspect of housing with which we are all very familiar—waste management. A Performance Requirement serves to call attention to a problem, and it identifies the context of the problem. However, it does not satisfactorily identify nor define the problem in terms of the key attributes to be used in judging the adequacy of proposed problem solutions. The characteristics by which a problem is to be defined and by which evaluation may be made of whether or not requirements are being met are called *Performance Criteria*. Most problems have many facets and require the use of multiple criteria which differ in importance. Thus, for example, the criteria for a household waste management "solution" include consideration of health effects, of property value effects and of aesthetic effects with differing importance being attached to each.

A Performance Requirement calls for a solution to be offered. Performance Criteria give the set of characteristics that solutions must have. What happens when *two* solutions are presented? A decision must usually be made to adopt only one and, hopefully, that will be the one that is better from the standpoint of cost and of effectiveness considered together. To be able to make such decisions requires that methods of measuring cost and effectiveness be adopted—even if they are at first crude and approximate.

In order to be able to evaluate alternative solutions that are competing for adoption, it is necessary to have a set of practical measurements that can be used to obtain an "effectiveness" score for each. What is needed is a set of tests and measurement methods that are not means biased; they should not favor any one candidate solution. Being practical and unbiased, a good *evaluation technique* will enable the scoring of any and all candidate solutions in such a way that the one with the highest score will be the one that provides the greatest amount of problem solution. Realistically, some criteria are not readily amenable to quantitative measurement. Simulation techniques may be useful to determine whether the proposed solution is satisfactory or unsatisfactory. The application of expert judgment may sometimes be the best evaluative technique available. At times, statistical interpretation of lay judgment may be the most appropriate metric to use. Whatever the case, a public act of measurement is essential to the performance concept.

When a Performance Requirement has elicited sufficient interest to engender the development of Performance Criteria and Evaluative Techniques, then it is likely that an appeal will be made to technology for a solution. Usually this means specifying what is needed in a way that will communicate in the engineering/scientific community. The fundamental performance documentation that may be used for this purpose is a *Performance Specification*. A Performance Specification comprehends all of the information in the underlying requirement and criteria. It also includes the evaluative techniques and it identifies the range of scores within which solutions must fall if they are to be considered acceptable.

With this understanding of the performance concept, let us return to our illustration of a "hard" specification for an electric razor. The given solution calls for cutting off hair as the method. It precludes the unbiased consideration of such methods as pulling out facial hairs and killing the hair-producing cells. In comparison, the fundamental Performance Specification for a "facial hair control system" should promote the consideration of all such methods. It should permit the introduction of newer, better, or cheaper means than the electric razor, if the technology can produce them.

Performance specifications can be written which are completely unbiased about means for solving the problem, or they can be written so that they are somewhat restrictive about the means without being so narrowly restrictive as a hard specification. For example, a performance specification might be written which covers all means for freeing the face of unwanted hair. This we could term a *fundamental* performance specification. Alternatively, a specification might be written to cover all means for cutting hair from the face. Such a specification would encompass safety razors, straight razors, and electric shavers, but would exclude tweezers for pulling out hair and methods of killing hair roots. A more restrictive performance specification could be written for all electric shavers. This would exclude safety razors and straight razors, but would still include a large number of alternatives. Specifications may be derived from a fundamental performance specification by restricting the means of achieving needs satisfaction. For the purposes of this presentation, we will refer to those specifica-

tions which are completely means unbiased as *fundamental* performance specifications, and those which apply to families of solution means as *derived* performance specifications.

In other words, as one approaches the employment of fundamental performance specifications to seek problem solutions, the number of effective solutions from which a choice can be exercised increases.

Relating the performance concept to housing, let us look at one of the categories of performance expected of housing—waste management. A fundamental performance specification might, for example, define the maximum level of waste to be tolerated in the house with no mention of means. A derived specification would address the problem from the point of view of establishing plumbing requirements. A more restrictive derived specification would specify employing a hydrostatic head as a power source. A hard specification would contain a bill of materials to be used, hardware locations in the structure, methods for joining pipes, etc.

The performance concept includes an hierarchical set of statements that define the following: performance requirements, criteria, specifications, standards, and codes. We have already discussed performance requirements, criteria, and specifications. *Performance standards* can result from specifications. If the measurement techniques are reproducible, and the requirements are reasonably common ones, a duly constituted body may issue specifications as a standard to be referenced by others, or it may become a de facto standard by common usage. A *performance code* is, in effect, a performance standard that has been adopted by a regulating body and put into practice in a legal sense.

Evaluative Techniques

Evaluative techniques may conveniently be divided into two categories: (1) Objective measurement; and (2) Subjective measurement. Objective measurement involves direct measurement by scientists and engineers through the use of apparatuses that provide quantitative results, expressed numerically and with known limits of accuracy for the measuring device including its operation.

As the first example of objective measurement, let us look briefly at the measurement of time, one of the four basic standards described earlier as making up the central core of the NMS. On October 13, 1967, the 13th General Conference on Weights and Measures decided that [3]: "The unit of time of the International System of Units is the second, defined in the following terms: The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the fundamental state of the atom of cesium-133."

You may ask, "Do we really need a clock that keeps time to a second in 30,000 years?" Actually the need for timing accuracy in such fields as satellite tracking, rocket control, and astronomical observations is far from met. We must remember that there are almost 10^{11} microseconds in a day and that a radio signal travels 300 meters in a microsecond. We use radio waves to measure distances and to track satellites which incidentally move at the rate of 9,000 meters every second. So we must have clocks that can keep in step to within a few microseconds over an extensive time interval. As a matter of fact, the NBS is now under pressure in the Institute for Basic Standards to improve our present time-keeping accuracy of 1 part in 10^{12} by two more orders of magnitude [4].

As a second example of objective measurement, let us turn from the basic core of the NMS to engineering standards: to measurement required by a building code on fire doors. Fire codes, to some extent, are performance-type codes because they frequently do not specify the materials to be used but rather their performance under certain conditions of test. For example, the Building Officials Conference of America Code on Fire Doors reads as follows [5]:

"Section 917.0. Fire Doors

"917.1 Fire Door Assemblies—Approved fire door assemblies as defined in the Basic Code shall be constructed of any material or assembly of component materials which meet the test requirements of sections 903 and 904 and the fire resistance ratings herein required.

Location	*Fire resistance rating in hours*
Fire walls and fire divisions of 3 or more hour construction	3
Fire walls and fire divisions of 2 hour construction	1½
Shaft enclosures and elevator hoistways of 2 hour construction	1½
Stairway and exitway enclosures except fire towers and grade passageways"	¾

The fire resistance is then measured by ASTM E 152–66, "Standard Method of Fire Tests of

Door Assemblies [6]." The method is precise with respect to: test assemblies (construction and size), time of testing, furnace temperatures, development of a time-temperature curve, etc. I am sure that this test, when carefully carried out, would measure the performance of fire door assemblies well, but would do so *only under those test conditions*. The method does not measure the performance of a fire door assembly in place in a building; i.e., under actual conditions of use. Therefore, such important factors as adjacent fire loads, enclosure geometry, and type of fire are not evaluated. Further, the fire ratings as required by the code bear only indirectly on factors critical to human safety; namely, temperature, smoke density, and toxicity of combustion products.

A final example of objective measurement describes the problem of measuring the performance of a building material *per se* and relating those data to the performance of the same material as part of a composite or sub-assembly of a building. As an exampl-, let us look at roofing asphalt.

More than 80% of the roofing used in the USA contains roofing grade asphalt as a primary component. Asphalt oxidizes and degrades under the factors that make up weathering. Thus, precise measurements of the photochemical degradation of asphalt should measure its performance in use. Chemists can make such precise measurements by infrared spectroscopy, for example. Photo-oxidation rates can be measured and roofing grade asphalts can be rated on this basis [7]. The order of photochemical stability is the same for both laboratory and outdoor exposure.

However, when asphalt becomes a part of a composite asphalt shingle, other factors, such as the nature of the roofing felt, the saturant, fillers, and protective granules, come into play. One can no longer be certain that photochemical oxidation of the asphalt is the rate-controlling factor in the degradation of a roofing shingle. Measurement must be made on the composite material. Chemists at NBS are now making such measurements through the use of gas chromatography, for example.

The problem does not end here. When one goes to a built-up roof made with asphalt, failures occur due to expansion and contraction, and a roof may crack, and leak, long before degradation through normal weathering occurs. Thus, performance must be measured by other methods. For example, a recent technique—measurement of the thermal shock resistance factor—has been used by NBS scientists to predict the performance of a built-up roof [8]. The measurement problem in building science is not one of more accurate measurements on materials, but that of meaningful measurement on larger aggregations of materials.

Subjective Measurement

Subjective measurement is based on value judgments of the human observer, or on human response to selected test situations; the results may be expressed in narrative form or by arbitrarily assigned numerical ratings.

Applied scientists and engineers often misuse subjective measurement in two ways: (1) employing subjective techniques where objective methods exist, or could be developed, and (2) analyzing data from subjective measurement as though they were made by objective methods. Engineers may make visual observations, convert these through an arbitrary rating system to numerical results, and use these results for subsequent analysis as if they were obtained through a truly objective (quantitative) process. Harper and Bratton [9], for example, developed a point system (Table 1) to measure the performance of plastics building materials upon exposure to weather. The entire rating system was based on visual observation, but once numbers were obtained, numerous curves were developed and some firm conclusions made as a result of direct comparisons.

TABLE 1. *Point system used in the evaluation of changes which occur on weathering of plastics**

Property	Maximum change in points	Relative weight	Weighted maximum
Surface fiber prominence	10	3	30
Color	10	2	20
Resin gloss	10	1.5	15
Subsurface fiber prominence	10	1	10
Warp and twist	10	0.5	5
Edge effect	10	0.5	5
Surface crazing	10	0.5	5
Subsurface crazing	10	0.5	5
Resin haze	10	0.5	5
Maximum point value			100

*Harper & Bratton, SPI Proc., Sec. 6E, p. 1 (1960).

A major upgrading in the measurement of the performance of building materials can be made if subjective measurement is completely eliminated in

those cases where objective measurement can be carried out. Today, scientifically-based analytical methods exist, or can be developed, to make quantitative measurements where engineers still use a visually-based rating system. The weathering of plastics is one area where such improvements can be made now.

Let us turn our attention now to the realm of uncontested subjective measurement, and as an example refer to the visual environment. William Lam, in a report prepared recently for the IAT on performance standards for low-income housing, had the following to say about the existing standards, procedures, and test methods for the visual environment:

> "None of the nineteen existing industry or national standards, Federal or other published specifications, or foreign standards, that was examined has any useful performance tests for existing natural or artificial lighting systems pertinent to recommendations for use in low-cost housing.
>
> "Among building codes in the U.S., those that have daylight requirements (some do not) express them in terms of window area, rather than performance with regard to view or light. The objectives of the requirements are not described. For artificial lighting, the range is from no requirements at all to describing what rooms should have lighting; a few list quantity requirements. None of these provides useful guidance to the purpose and qualitative aspects of the requirements [10]."

Mr. Lam suggested the following courses of action for further development of performance criteria for the visual environment in housing:

> "Subjective testing procedures should be used to establish confirmation of the numerical values assigned to the performance requirements proposed, which were based on judgment. Procedures might include: (1) developing standard measuring procedures by which to rate existing housing units as meeting, or not meeting, the proposed performance criteria; (2) developing survey questionnaires to measure user satisfaction, and use of artificial lighting in daylight; (3) evaluating the accuracy of the ratings in predicting user satisfaction, as compared to the accuracy of present types of specification requirements. An accurate and inexpensive technique (using scale models) should be developed for testing proposed designs against the performance requirements [10]."

Hopkinson, in his paper entitled "The Evaluation of the Built Environment," makes the following comments on sensory evaluation [11]:

> "The architect and the environmental engineer would be relieved of much uncertainty if the success of their work could be evaluated entirely by physical-measuring instruments. However, the final judge of the success of a building must be the human occupant. Consequently, a fruitful field of research in the environmental sicences is the development of methods of sensory evaluation and of the application of these methods to yield useful design tools to aid the architect in his work."

He cites three main objectives. "First, the need is to set standards. It is necessary to understand the nature of human sensory responses to physical factors of the environment, so that building standards can be set which have a sound basis in terms of the physiological and psychological needs of the human occupants. The second objective is to develop technologies for achieving these standards, technologies which are of architectural and engineering validity. The third objective is to develop methods of sensory evaluation in the completed building which will reveal whether or not these standards have been met at a subjective level. Physical measuring instruments can check physical standards; human meters must check human requirements.

"In the search for the best methods of sensory evaluation of the environment, the architect and engineer have had to study the work of the experimental psychologist and the physiologist, but always bearing in mind that their end point is the design of buildings and not the study of the human being."

Scientists and engineers, and perhaps architects too, who deal generally with hardware solutions or, in laboratory research, with objective measurement techniques, tend to be skeptical as to the reproducibility of the human meter as an evaluative technique. Eberhard listed the following to demonstrate the ability of human meters [12].

1. "Some humans have 'perfect' pitch.
2. Experts can visually identify paintings by their

date and school of painting and even by artists if well known.

3. Experts can recognize musical themes and:
   (1) Identify entire musical composition of theme
   (2) Identify school of music if other information is unknown
   (3) In some cases can recognize performing artists or conductor
4. Anyone can recognize famous people from a good caricature.
5. Experts can identify wine by taste in terms of vineyard from which it comes and years of harvest.
6. Experts can differentiate between 1000's of fragrances by smelling.
7. Most blind people can sense the space around them by sound signals.
8. Most blind people can do a number of things, including reading, by tactile senses.
9. Mothers can test the temperature of baby's milk by a few drops on the wrist."

Heath, in a recent paper on "Problems of Measurement in Environmental Aesthetics [13]," stressed the need for measurement and proceeded to describe techniques useful in the field. He expanded the theories of Hopkinson, stressing human meters, measuring scales, models, and analysis of responses. He concluded his paper with the following comment on environmental aesthetics:

"The present state of aesthetic studies resembles that of the research work of the chemist who, after some years labour, was able to report that he had discovered a substance which was colourless, odourless, tasteless, and useless. There is nothing clearly established, no chain of cause and effect, no quantitative relationship which could be of the slightest assistance to anyone. There are a large number of theories, mostly wordy, confusing, and serving rather to rebut past philosophical opinion than to unify the considerable but scattered body of factual data now becoming available. The subject urgently needs a staunchly empirical approach and a determination to develop methods which can be applied to practical difficulties. It is for this reason that this paper has concentrated on methods of measurement; for if we can solve the problems of measurement, sound theory and practical application will follow."

Conclusion

With respect to performance, I would modify Mr. Heath's last statement to say, "If we can solve the problems of measurement, both objective and subjective, practical application of the performance concept in building *can* follow." The conditional form used here is to emphasize that automatic implementation of the performance approach will not occur as a function of availability of appropriate evaluative methods. A coordinated effort must be made by all concerned with the entire building process. The performance of buildings can be measured, but it will not be easy and to a large extent will be done in an incremental manner ranging from measurements on simple materials to whole structures. Methods at our disposal are the ever-improving analytical techniques of the physical scientist and the ability of the engineer to evaluate whole structures. With respect to subjective measurement, the combined talents of the architect, engineer, physical scientist, and behavioral scientist must be applied to make the building more responsive to the human occupant. Greater emphasis of the human being as a meter is required both prior to the design of a building and after its occupancy. I am encouraged by the progress we have made here in the IAT–BRD in tackling first hand the measurement of the performance of buildings—from simple materials to entire structures. We have much to do, but the papers you will hear during this conference will, I believe, convince you that we are gradually making inroads towards the implementation of the performance concept through a key ingredient—measurement.

References

[1] Huntoon, R. D., "Concept of a National Measurement System," Science, **158**, 67 (1967).

[2] Eberhard, J. P., "The Performance Concept: A Study of Its Application to Housing," National Bureau of Standards Report No. 9849, **1**, 47 (1968).

[3] National Bureau of Standards Technical News Bulletin, **52**, No. 1, 10 (1968).

[4] Huntoon, R. D., "Measurement System of the United States," talk presented at the 1966 Standards Laboratory Conference, NBS, Gaithersburg, Md., May 9–12, 1966.

[5] Building Officials Conference of America, Basic Building Code, Section 917.0, 4th Edition, 232 (1965).

[6] "Standard Method of Fire Door Test Assemblies," ASTM E 152–66, 1967 Book of ASTM Standards, Part 14, 427 (1967).

[7] Wright, J. R. and P. G. Campbell, "Determination of Oxidation Rates of Air-Blown Asphalts by Infrared Spectroscopy," J. Appl. Chem. (London), **12**, 256 (1962).

[8] Cullen, W. C. and T. H. Boone, "Thermal-Shock Resistance for Built-up Membranes," National Bureau of Standards Building Science Series No. 9 (1967).

[9] Harper, R. C. and F. H. Bratton, "Contour Matched Metal Molded Glass Reinforced Plastics for Outdoor Use," SPI Proc., Section E–6, 1 (1960).

[10] Eberhard, J. P., "The Performance Concept: A Study of Its Application to Housing," National Bureau of Standards Report No. 9849, **1**, 247 (1968).

[11] Hopkinson, R. G., "The Evaluation of the Built Environment," Inaugural Lecture, University College, London, November 11, 1965.

[12] Eberhard, J. P., private communication.

[13] Heath, T. F., "Problems of Measurement in Environmental Aesthetics," Architectural Science Review, p. 17 (March 1968).

THE USER AS THE BASIS FOR ARCHITECTURAL AND URBAN DESIGN

Michael Brill

Building Research Division
Institute for Applied Technology
National Bureau of Standards

I'd like to talk about an evolution so rapid that it has many of the earmarks of a revolution. This is a report of things that are happening now to change our building technology: The entire process of how we build and all the products of that process. This evolution is called the systems approach and is an intellectual technology—a way of looking at problems, and a way of solving them. It is not necessarily a hardware-rich technology composed of reels of computer tape and electronic control gadgets (although it may employ these), but rather an elegant intellectual social instrument and a market mechanism to assure us that our new buildings and communities will be really responsive to our needs. It has as its hallmark emphasis on analyzing the intended users of physical environments and flexibility in developing solutions to their problems.

Let us try then to understand this approach which has as its central consideration you, the user. All physical environments, like buildings and building groups, and communities and cities are made for a purpose. They are intended to help achieve our goals by enabling a certain level of human performance to be reached. All buildings are made to help users operating within a particular system achieve their goals. For instance, schools, homes and hospitals are parts of an educational system, a residential system and a health care system. Each of these systems in turn is part of, and serves, the next larger system, perhaps a community. We could continue on up this ladder describing systems, but won't because we are unclear about where it ends. It's much more complex than I have stated, for there are relationships and interactions between systems which are delicate, precise, and not understood. We often only become aware of these relationships when we see that decisions made and actions taken in one facet of our environment have profound effects elsewhere, calling attention to a relationship previously unknown.

Many of these effects are unwanted and some are disastrous—most of them are not easily predicted, for we do not know how our building and community systems really operate. Even where we can predict this unwanted output, we are often still unable to prevent it, because we cannot measure it accurately, and have difficulty in making decisions about priorities involving costs and benefits. Because of these and many other problems, it is felt by many that the present techniques for designing and building are not working well, the results being that our present environments are inadequate to our needs, in both quality and quantity. I wish to imply that if the product is unsatisfactory it is because the process which produces it is also unsatisfactory.

Further, the present "system" for designing and building is clearly inadequate to the needs of the future. In less than a decade we must more than triple our output of housing (and of course, of other community buildings and services,) but we find that the home building industry at present is producing at a near optimum in terms of economies of scale [1,2,3].

Because this building process can not meet our needs, it is being changed. Because the quality of building substantially alters our activities, behaviors and emotions [4], the goal of this change is to devise a process which will assure a better fit between buildings and communities and the needs and aspirations of all of us who use them. I'd like to examine the problems of reaching this goal and attempt to focus down on the specific issue—the user as the basis for design which is the central concept in the systems approach.

We have stated that there are dysfunctions in the physical environment, that they are process-generated and maintained and that they are both quantity and quality problems. I will not deal with the quantity aspect, the not-enough-to-go-around problems, but with the quality, or poor-fit problem. They are not really wholly separate issues, but I can't deal with the whole topic, and I apologize for any lapses in clarity which arise from dealing with only one portion of a problem.

In concentrating on the user, I've also selected

the human user side of the poor-fit problem, rather than the environmental side; the software, rather than the hardware. Again, they are linked, not separate issues. I will give some examples of why we want to focus on the user—why the user is important:

A systems view of federal office buildings for example, is that they are simply a piece of a government information processing system, along with men, machines, and methods. If we could process information without buildings (as someday we might) we would do it. We have studied [5] the cost of this information processing system and find that, over 40 years, 2% is in the building itself, 6% is in the operation and maintenance of the building, while 92% is in the people; that is, the users' salaries, therefore, we are concerned with the user, not the building, as the cost-sensitive element. The same kind of analysis, with similar results, has been made for hospitals. Analyzing housing is more difficult, but our experience shows that many housing projects with high hardware standards have become instant slums, the obvious result of user or social problems. To quote the book, The Exploding Metropolis, [6] "Once upon a time (says a close student of New York's slums) we thought that if we could only get our problem families out of those dreadful slums, then papa would stop taking dope, mama would stop chasing around, and junior would stop carrying a knife. Well, we've got them in a nice new apartment with modern kitchens and a recreation center, and they are the same bunch of . . . they always were."

That may be an overstatement of the problem, but not by much. We have heard too much of technical solutions to technical problems, when the problems are obviously social in nature. I won't pretend that buildings alone can solve social problems, but when the occupants have no control over the building process and over buildings themselves, the problems these buildings are intended to solve are more likely to be compounded then alleviated. We feel painfully ineffective when trying to get something we want in complex situations, like our building process. John Eberhard, a leading building process theorist and systems educator, has called it, simply, "loneliness." We have become attenuated from large parts of our environment and feel distant from where the decisions which affect our lives are made. In many areas outside of building, this has been realized and corrective action taken. Some of the results are school decentralization, neighborhood city halls, community mental health centers, and the community participation called advocate planning.

And now, in buildings, we believe we have a mechanism which shortens this distance, which enables us to be heard by men who make decisions which give form to the things which surround us. Let me describe the distance there is now between the users of buildings and the makers of critical parts of buildings. For example, a region grows fast and a lot of students need a high school. The school board senses this, gets the money, and comes to the architect. They tell him what they think the students need. He produces what he thinks is an appropriate design response, and the board approves. A general contractor gets the job of building it, and he in turn, hires subcontractors to supply and install large portions of it. They in turn buy products from a manufacturer who is six steps removed from the users, in this case, all the students. The systems approach, concerned as it is with performance, not products, is shortening this chain. We are developing ways to let students (and other users) enter into a dialogue with the manufacturers, to let them know what they want and need in their physical environments. If makers could be sure that a product was wanted and that it was guaranteed to satisfy, wouldn't they make it? We believe that this dialogue between the users and all of the makers is the critical issue today, and that the Users' Needs are the critical element in this dialogue, and, therefore, in the design process.

Users are affected in three ways by physical environments—physically, psychologically, and socially. Where there is a poor fit and the user has limited choice, crisis conditions are generated. Physically a poor fit generates accidents and health hazards, and can aggravate a poor fit psychologically and socially which leads to impairment of mental health and may be one of the root causes of riots in our streets. These social disasters are the feedback which give a sense of urgency to our efforts. Where there is a poor fit, but the users have choices and options, they will alter the environment, leave it, or not "buy" it in the first place. This second case demonstrates that "fit" is not only a social instrument, but a market mechanism as well. It is clear, however, that the first case is now the more prevalent, where poor fit is accompanied by limited choice. This is a non-constructive situation as a free market mechanism, and it is here that the government may, perhaps, assume the burden of or-

ganizing the market and analyzing the user.

If we could find a way of assuring a good fit, (physically, psychologically, and socially) between users and their buildings and communities, we could assure the users' satisfaction with that environment. And so we have turned to a form of "market research:" finding out what users need and want and through the performance concept within the Systems Approach, helping makers design and procure buildings and communities responsive to these needs and wants. If user needs are explicitly stated, and form the value structure of the design brief, and user satisfaction is both the goal and the basis for post-facto evaluation of the result, we ought to be able to assure a "good fit," a useful social instrument and a healthy market.

I have two biases which should be made explicit (if they are not already obvious) at this point: one is that the users' psychological and social needs are more important than the complete fulfillment of his physical needs. This is not meant to denigrate the physical aspects of "problem" environments, but rather to alter an historical emphasis we have placed on hardware. Users themselves substantiate this bias by placing great value on rather limited and restrictive space in such areas as Georgetown, Beacon Hill and Greenwich Village. The second bias is not so easily substantiated. That is, that the best condition is not the adequate, neutral fit, but a condition where needs and wants are actually exceeded by the performance of the environment, where there is an excess of quality—this, I believe is the arena in which personal growth and enrichment occur. These two biases have had an impact on the methods developed in this paper.

In gathering information about user needs, we must first define the user, develop methods for ascertaining his needs, and then amass the data, in this case, statements of need in as rigorous a fashion as the state of the art permits. I want to clarify the idea of a need. In the systems approach, we do not specify solutions. We only specify the need or performance which must be accommodated, and essentially delegate responsibility for solutions to someone closer to the actual making of things. This allows him to examine alternatives and does not unnecessarily restrict him in his search for a solution. When a user says he "needs" a heavy door and a complex lock, he is describing a solution, not a need. There are many alternatives to his real need, which is security. By being explicit about security, we make it possible to examine, evaluate and select from a spectrum of hardware alternatives which will produce the desired result.

This example points up two problems in developing user needs statements: all of us, as users, have had our imaginations molded and constrained by our surroundings. We do not think we need things we have not thought of, nor had. A case in point is: when the New York State Council on the Arts wanted to determine what facilities would be required for the performing arts, it interviewed not only actors, managers, and directors but also dancers, who have traditionally had grossly inadequate facilities and are the gypsy orphans of the theatre. The Council asked them, "Now, how many showers would you like?", they were met with a dancer's unbelieving stare and the words . . . "you mean . . . we could have showers?"

The second problem is that users are not experts in many areas, such as health and safety needs, or the need for structural stability, and cannot state their needs. Experts must do this work. The users, however, are the most sensitive to those social and psychological factors in the environment which affect them, but may need help in articulating these factors.

We have not fully solved the preceding problems, but nevertheless are now developing a method to ascertain user needs. [7] Our basic concept is that between the statement of a user's need and the environmental solutions that satisfy them there must be a bridging statement which specifies what attributes must be present in the space in order that the user's need may be met. As a simple example, in a study environment, a user's need is to be able to read. The bridging statement, which we call a "Required Spatial Attribute," is in terms of illumination—not lighting fixtures. Lighting fixtures are solutions and not yet our concern in this process. We specify how much illumination must reach the eye from the message surface to allow the designer to select the method which satisfies this requirement from alternatives which might include windows, lighting fixtures, illuminated messages (like slides or movies), or more sophisticated illumination methods not yet developed. We have developed techniques to display user needs and to ascertain required spatial attributes.

There are about 15 major projects [8] in this country and Canada in which buildings are being procured on the basis of user needs and systems techniques. The statement of user needs is proving

successful as the basis for actual performance specifications in many of these projects.

User needs can also sharpen our cost/benefit evaluation tools, for they give us a more precise understanding of the user side of the equation, the benefits. Too often, we make decisions which we know intuitively to be questionable from the user standpoint, but not having data to support our beliefs, we are forced to decide on the basis of the easily gotten information, the costs. When cost is the only yardstick available for evaluating alternatives, reducing them can be the only goal.

Finally, we employ user needs as an evaluative mechanism. We can simply match the designed, built environments to the needs that generated them as a way of checking results systematically. With it, we generate a different, more constructive kind of feedback than we now have. At present, we employ a crisis model of feedback, one form being the aftermath commission in the wake of every upheaval. If concern for user needs could be an ongoing, constant effort to help us adjust our building programs to changing user goals, we would have a dynamic, online feedback mechanism.

In order to prevent your clogging the postal system with requests for our "latest model" user needs, let's talk about the problems we have encountered which have slowed up the work. A major one is the difficulty of clearly stating goals at a level where we can start to dissect them and develop alternatives. National and even local goals and policies are nowhere clearly stated. It was thought that the soft sciences—policy studies, sociology, anthropology, ecology and psychology—would be a great resource for deriving and examining goal statements. There are unexpected and, as yet, unexplained difficulties in transferring intellectual technology between disciplines. Another, and perhaps critical, problem has been the lack of funds to carry out this research. We tend to support those ideas with which we are familiar. As a country, we have grown great, largely as a result of our capacity to make hardware of excellence quite cheaply. We tend to want to do that to solve all our problems, and as a result place our emphasis on hardware research while providing only minimal support for research into user needs. Such research does not come cheaply.

The question often raised is why should user need studies be supported heavily, especially in a time of intense competition for resources? Because it is a way, one of the few ways, to make what we build more responsive to the people who use it—to make it theirs, and to generate pride of use. Intuition is no longer a sufficient base for the job. And as John Gardner warned, upon leaving his position in the President's cabinet, "we are in deep trouble as a people; and history is not going to deal kindly with a rich nation that will not tax itself to cure its miseries."

The clear and precise delineation of this most basic information, what users need can and does give direction and provide a context for all other research into physical environments. It is basic to a healthy, enriching environment and a vigorous market.

Without this information, and the change in vision which automatically accompanies it, we have no real, rational, and systematic mechanism to prevent us from squandering scant resources, from doing what good poker players warn against, "Throwing good money after bad."

References

[1] The Performance Concept: A Study of Its Application to Housing, Vol. III, "A Pilot Study of the Economies of Scale Related to Residential Construction", prepared by the National Association of Home Builders for the National Bureau of Standards. Available from Clearinghouse, Springfield, Virginia 22151.

[2] The Impact of Social and Technical Change in Building. Gary Stonebraker for Building Systems Development, Inc.

[3] Recent Studies by Professor Arnold Rosner, College of Architecture and Urban Planning, University of Washington, Seattle, Washington.

[4] Inadequate Housing Space and Social Organization by George Gray, Dept. of Anthropology and Sociology, University of British Columbia, 1967.

[5] Building Systems Project: Status Report, prepared by the Institute for Applied Technology, National Bureau of Standards, 1967. Available from Clearinghouse, Springfield, Virginia 22151 (No. PB 176 959).

[6] "The Enduring Slums" by D. Seligman, The Exploding Metropolis, Chapter IV, by the Editors of Fortune.

[7] The Performance Concept: A Study of Its Application to Housing, Vol. I, II, III, prepared by the Institute for Applied Technology, National Bureau of Standards, Washington, D. C., 1968. Available from Clearinghouse, Springfield, Virginia 22151.

[8] *a.* First California Commission on School Construction (Contract Documents and Performance Specifications), Palo Alto, California, July 1963.

b. Schoolhouse Systems Project #1 (Performance Specifications), Florida State Department of Education, Tallahassee, Florida.

c. University Residential Building System (Contract Documents and Performance Specifications), The University of California, Berkeley, California 94720, June 1967.

d. Research in School Facilities, Contract Documents and Performance Specifications, Montreal Catholic School Commission, Montreal, Quebec, Canada, June 1968.

e. Study of Educational Facilities, The Metropolitan Toronto School Board, SEF Report T1, Toronto 7, Canada.

f. Building Systems Project: Status Report, prepared by the Institute for Applied Technology, National Bureau of Standards, 1967. Available from Clearinghouse, Springfield, Virginia 22151 (No. PB 176 959).

g. Academic Building Systems (an expanded version of Reference 8*a*).

h. Schoolhouse Systems Project #2 (Performance Specifications), Florida State Department of Education, Tallahassee, Florida.

i. Pittsburgh Great Schools Project, Pittsburgh, Pennsylvania.

j. Laboratory Systems, Binghamton, New York, prepared for State University of New York Construction Fund.

k. Model Cities Experiment, Department of Housing and Urban Development, RFP.22.68.

l. Project for National Institute for Mental Health. Work being done by Institute for Applied Technology, National Bureau of Standards, 1968.

SESSION II. EVOLUTION OF PERFORMANCE SYSTEMS METHOD

T. E. Ware, Chairman

332-247 O - 69 - 3

THE PERFORMANCE/SYSTEMS METHOD (NBS–PUBLIC BUILDINGS SERVICE BUILDING SYSTEMS PROJECT)

Robert W. Blake

Building Research Division
Institute for Applied Technology
National Bureau of Standards

Abstract*

The School Construction Systems Development Project in California and the Polaris Systems Development Project in the Department of Defense are discussed as background for the NBS–Public Buildings Service Building Systems Project. Distinction is made between a Building System, a physical thing and the Systems Approach, a methodology.

The Project is concerned with a Federal Office Building for use by a Federal tenant. Reasons for selecting this type of building for the Project rather than a hospital or general purpose scientific laboratories are given.

For an initial effort, application of the performance/systems method to an entire building was deemed too ambitious. The floor-ceiling sandwich and space dividers system was selected for the Project. This includes the finish floor, the structural floor, the finish ceiling below, all of the accompanying services between ceiling and floor and the space dividers. These components account for about 30 to 40 percent of the initial building cost and are site and land independent.

A study was made of four Federal office buildings occupied between 1959 and 1965 and conclusions from the study were checked against a sample of nine buildings occupied during the same period. Floor size, ratio of length to width, tenancy size address size, etc., are summarized.

A matrix was constructed with built elements as column heads and spatial attributes required by the user as row designations. Built elements are structure, heating-ventilating-air conditioning, utilities, finish floor luminaires, ceiling and space dividers. Spatial attributes are conditioned air, illumination, acoustics, stability and strength of materials, health and safety, planning, activity support, esthetic, maintenance and improvement, and interface. The 70 intercepts of the matrix contain information appropriate for the need. This matrix was expanded to include the building process and the support system of the user of the building.

The needs are expressed in the matrix in terms of performance and not hardware requirements. Methods for determining conformance to requirements are selected or developed. The manufacturer has the freedom to use his initative in developing or supplying hardware to meet the requirements.

The high cost to the user of the building compared to the cost of the building emphasizes the importance of constructing a building that increases the efficiency of the user.

The Project is being documented in a manner that will enable parties that were not involved in the original development to use and expand the methodology.

It is hoped that the methodology will be found suitable for transference to residential construction to help meet the enormous need for adequate housing.

*Abstract prepared by the editors. The speaker did not submit a manuscript.

EUROPEAN SYSTEMS FOR EVALUATION AND APPROVAL OF INNOVATIONS IN BUILDINGS

Bruce Foster

Building Research Division
Institute for Applied Technology
National Bureau of Standards

Introduction

In an organized society it is necessary to regulate the design and construction of buildings to meet several different types of requirements. Building codes are concerned primarily with the life-safety and health of the building occupant. Exit adequacy for an emergency, fire endurance, and sanitation of plumbing are examples of such requirements. Additional concepts are imposed by those who insure buildings. For example, in the case of fire insurance, in addition to building features designed to insure safe evacuation by occupants of the building, more stringent requirements are needed to confine an unwanted fire so that firemen can save the structure and minimize property damage. Still other regulations may be called for by the mortgage industry. The building must not only be constructed to remain safe, it must in addition, continue to be marketable. This involves control of architectural features, but more importantly consideration of the durability of materials and components to insure adequate long-time performance.

In developing building regulations, use is made of existing standards; standards for materials, products, traditional methods of construction, and codes of practice on material use. These have been, and still are, largely of the prescription type. They describe materials and parts of building systems which, through experience gained from long usage, have been found to meet a range of user requirements. When new materials, products, or systems are offered for use, an evaluation of the innovation is usually necessary, and this is normally accomplished by comparing the performance with those materials already deemed to be satisfactory. Such a comparison immediately requires consideration of the properties which lead to desirable performance by both the old and the new solution. With the great recent advance in technology, many new materials are being developed, old materials are being put to new uses, and composites of old and new materials are being made. The emphasis on performance requirements, therefore, necessarily has become much greater. There are indications that a switch to performance requirements to facilitate acceptance of new products is absolutely necessary if the full benefits of technology are to be realized. The shift requires a new kind of thinking, the development of many new testing procedures, and the development of techniques for rendering expert judgment in those areas where testing techniques have not been, or possibly cannot be, developed.

In previous papers of this Symposium on Performance of Buildings, there has been considerable discussion of user needs. In translating user needs to final specifications, it is necessary to go through several intermediate steps, the first of which may be a translation of user needs into a physical description of what the desired solution must accomplish. The next step is specification of specific materials and products which possess the desired physical attributes. In the case of a waste, drain, and vent system it is necessary to decide the typical chemicals and temperatures to which the piping is likely to be exposed, what structural properties are needed, any effect the specified solution may have on the fire integrity of the building, etc. Then it is necessary to develop detailed specifications for the specific solutions which will satisfy the performance requirements, and which will also be suitable to characterize the materials or products that will meet these requirements. These are needed for quality control and for use as purchase specifications. Examples of such latter specifications are those used for materials such as cast iron drain pipe, copper drain pipe, cement-asbestos drain pipe, and plastic drain pipe.

The process of assessing and accepting an innovation is frequently far from simple; and, in many cases, it requires the development of new testing techniques and the assembly of expert opinion. The process existing now in the United States might be characterized as only moderately satisfactory. Usually test data and records of experience are col-

lected by a manufacturer and submitted for assessment and approval by model code groups or by regulatory officials in code jurisdictions. Organizations such as the National Sanitary Foundation or the Underwriters' Laboratories may develop testing procedures and apply them for a fee to products submitted by the manufacturer.

For a number of years we have been hearing from foreign colleagues in the building field about the development in Europe of new systems for evaluating innovations in building materials, products, and systems.

A. Allan Bates, then Chief of the Building Research Division, in a paper, "A Proposed System for Innovation of Building Construction," in the July 1966 issue of ASTM Materials Research and Standards suggested that the time had arrived for debate on this subject and for study of the need for establishing in the United States a more central system for evaluating innovations. As a start, I have had the opportunity to interview a number of people in six countries on many aspects of the performance evaluation systems used in European countries. All cooperated fully in discussing problems of evaluating innovations, and the procedures employed in so doing. The systems used in several countries will be described below, with particular emphasis on those of France and Great Britain.

France

The first of the modern systems to be established in Europe was the French Agrément (approval) System, which has been in operation for about fifteen years and is furnishing the prototype for this type of activity throughout most of the world. Certain conditions in France make such a system almost imperative. The most important of these is the ten-year liability imposed on the contractor for all aspects of the building, even paint. This liability makes the purchase of insurance almost a necessity. The Insurance Industry is understandably conservative, and therefore is reluctant to insure innovations that are not proven by service records to perform satisfactorily for a period equivalent to the life of the required liability.

The Agrément System was developed to reduce the magnitude of this restraint on the introduction of innovations in building. Established by decree of the Ministry of Construction, the system is operated by the Scientific and Technical Center of Building (C.S.T.B.), an organization of the Federal Government. The C.S.T.B. is charged with a number of functions including the development of an understanding of human needs; the effects of climate; and the chemistry and physics involved in such areas as acoustics, lighting, ventilation, durability, and stability.

The Ministerial Text which established the operating procedures of the Agrément System provides for a committee, of general competence, to insure uniform policy and to advise the director of C.S.T.B. The fourteen members represent governmental organizations, architects, manufacturers, and contractors. They are appointed for two-year terms by the Ministry of Construction and are selected from 28 nominees proposed by the C.S.T.B., after consultation with various segments of the building industry. The Director of the C.S.T.B. serves as chairman of the committee.

In addition, there are about 18 specialized committees, appointed by the Director of C.S.T.B. upon recommendation of various segments of the building industry. Each specialized committee deals with a specific area such as floors, ceilings, etc., and is composed of 15 to 25 experts in that particular technology. All interests are represented on the committee to insure that the Agrément certificates will have ready acceptance. Members must be technically competent, and must be chosen both for their objectivity and their desire for progress. The decision to issue an Agrément certificate requires both tests and judgment. The tests are performed by C.S.T.B. The judgment is furnished by the committee and by experts from the C.S.T.B. staff. Philosophically, the judgments need to be "not foolish" and "not conservative." If consensus is not reached early, more work is done. Thus far, it has always been possible to establish a consensus.

The request for an Agrément certificate must come from a manufacturer or contractor, and the application must specifically state the area of application and the method of use. A process for which an Agrément certificate is given may be licensed to another organization provided that full specifications are available which will insure that the product of the licensee is equivalent to that of the holder of the certificate. However, a limitation may be placed on the product limiting it to one manufacturer or even to one location of manufacture. Full disclosure must be made which will define the material, equipment, or process; its structure, composition, form, fabrication, the means as well as the conditions of its use, estimates (or demonstration) of its usefulness, and information on quality control

procedures. The potential recipient must agree to respect the obligations defined by the regulations; and to submit to any examinations, sampling, tests, or experiments, in shop, factory, laboratory or on the job, which may be deemed necessary by C.S.T.B.

The holder of a certificate may not mention the Agrément in contracts unless the user is furnished the entire document. The certificate cannot be used in advertising or promotion after termination of its period of validity.

An Agrément certificate can be obtained only for an innovation. Traditional materials or decorative materials are not eligible. The material or process is reviewed from the standpoint of safety, usefulness, and durability; with due account being given to climatic conditions and the building regulations. The decision on issuing an Agrément is made by the director of C.S.T.B. The certificate is valid for a period of three years and then is subject to renewal. There is no limit on the number of renewals, although normally a standard is established as soon as feasible. The renewal system permits a manufacturer to modify and improve his product continually. Modification is more difficult with a standard than with an Agrément certificate because the latter is applicable to only one manufacturer. Changes in the material or process during the life of the certificate must be submitted in advance for review and potential reissuance of the Agrément certificate.

The Agrément is subject to continual review by C.S.T.B. both with regard to current production and the performance in use of previously manufactured material. The certificate may be terminated for cause by the C.S.T.B. at any time. Certificates are published as official documents by the C.S.T.B. Suspensions or retractions of existing Agréments also are published. An appeal procedure is provided. The expense of the examination made to facilitate the decision by the C.S.T.B. on request for an Agrément certificate, or renewal, is charged to the requester. However, such charges do not cover the costs of developing new testing procedures required for many innovations, or for the cost of maintaining equipment and support facilities and technical personnel which contribute to the success of the program. It is estimated that the requester pays only about one-third of the total costs of the entire evaluative procedure.

The certificate is not a guarantee from C.S.T.B., particularly respecting continued quality of production. The Agrément is not a directive, and is not binding on anyone, but it is accepted by the insurance industry and code authorities.

The C.S.T.B. believes that emphasis should be placed on determination of user needs. It should also be noted that the question of durability is given prominence in the evaluating process. The research programs of the C.S.T.B. are directed toward both areas.

Great Britain

The Agrément Board in Great Britain was established about two and one-half years ago. The motivating force was the Ministry of Public Buildings and Works, rather than the liability insurance problem as was the case in France. The Ministry, responsible for about fifty percent of housing in Great Britain, desired to develop performance-type testing procedures in order to promote acceptance of innovation. The Agrément Board was furnished with a five-year subsidy. In general its operation is similar to that of France. The aims and procedures are described briefly in Agrément Paper No. 1.*

The Agrément appraisal is directed primarily toward technical matters and does not deal with decorative aspects or economics of use. An attempt is made to marshal available technical evidence to form an opinion on the probable performance in advance of extensive practical experience in use. The Agrément is an attempt to furnish independent assurance that a new and relatively unknown product will give satisfactory performance when used in a building. It makes practical application of the research knowledge available on the performance of materials in developing procedures for making the assessment. Since the evaluation is performance oriented, an attempt is made to assess the component in its proposed application rather than as a material or component for general use.

The Agrément Board, a government agency, depends upon another government agency, the Building Research Station, for the required tests and development of some testing procedures. The Board's own technical competence is augmented by that of the staff of the Building Research Station. Tests, however, can be conducted in other government laboratories and, in the future, perhaps in universities.

*July 1967, Lord Alexander House, Waterhouse Street, Hemel Hempstead, Herts, England.

The proponent of an innovation meets in conference with members of the Board, where he discloses the nature of his product (confidentially) and provides any information available on experience with use or testing data.

The manufacturing plant is visited, and the capability for quality control is assessed. The needs for tests and for consultation with experts are determined and costs estimated. Cost includes a factor for monitoring the performance after an Agrément is established. If a proposal is accepted, the tests are performed, and a judgment made on the implications of the test results. Also, assessments are made about those properties for which no tests exist and for which evaluation must be based on expert knowledge and background. Recommendations are then submitted to the Agrément Board, which makes a final decision. Unlike the French System, there is no formal special committee making a recommendation to the Director. The Agrément certificate is valid for a period of three years and may be renewed for one further period. The certified material's composition or process may be altered, provided the board is informed and concurs that such changes will not invalidate the value of the certificate.

The certificate applies to a specific manufacturer and the plant at which the product is made. It identifies the intended use and, where necessary, gives details of the construction, including any associated detail about method of erection or attachment to associated parts of the building. It summarizes the functional properties and, where appropriate, gives an opinion as to whether the construction containing the product in the manner specified appears to satisfy requirements in the building regulations.

The certificates are published by the Board and are available to all users. Manufacturers whose products have gained a certificate are free to use it, but only in an unabridged form.

The first Agrément issued was for a flexible damp-proof-course (through-the-wall flashing) material. The certificate lists the name of the product, the manufacturer, and the assessment. The latter states that the Agrément Board believes the product to be a satisfactory material for the intended use; that the material provides a barrier to transmission of water or water vapor, does not become sticky or tacky at high temperature, and behaves well in brickwork subjected to direct compression and to horizontal shear movements.

The certificate states that the composition of the product has been disclosed to the Board and that continuance of the certificate depends on continuance of the stated composition and on the quality control exercised to insure absence of pin holing or other defects.

The Board stated that in its opinion, the product satisfies the requirements of Regulation B1 (i) of the Building Regulations, 1965, in relation to the term "damp-proof" course, and the requirements of Great Britain's other three building codes.

On the subject of durability, the certificate states that forecasts rest mainly on a background knowledge of the materials of which the product is composed, on a study of its manufacture and of its physical properties as measured on new material, and on comparisons with similar materials accepted in British Standard No. 743. The Board's conclusion is that this product, used in the orthodox way as a water-resistant barrier wall, in normal circumstances, remain effective over the lifetime of the building.

The statement on expected durability is, to my mind, of very great importance, for it deals with the necessity to assemble expert judgment to assess factors of performance which cannot be adequately measured by accelerated tests. The background and competence of the Building Research Station Staff, together with any outside consultation deemed advisable, are available to make this judgment. In the French system the judgment is based on the knowledge of similar experts from the C.S.T.B. and the members of the special committee.

It was expected that the British Agrément System would become self- supporting by the end of the five-year subsidy. This estimate is now questionable, partly because of an unforeseen lack of suitable test methods to make evaluation of performance requirements. Also large amounts of time are spent in working out evaluation arrangements which are not accepted by the proponents, thus producing no revenue. Also, utilization of the staff and facilities of the Building Research Station constitute a form of subsidy.

The Agrément Board works closely with the British Standards Institute, and the work of the Board is looked upon as an important potential contributor of performance-type test procedures to the Institute. It should be pointed out, however, that in many cases a test procedure developed by the Agrément principle cannot fully satisfy the requirements for a standard. For example, Agrément test procedures for waste, drain, and

vent systems would be developed around lists of representative chemicals which the waste system must resist, required structural properties, response to temperature, etc. Such a specification has to be supplemented by individual solutions to the general problem, such as specifications for specific pipe materials. The intent of the latter is to characterize products made of specific materials, and deemed to satisfy the performance requirements by specifying chemical composition, flexural strength, and other related properties, both for purchasing and for quality control purposes.

The National Building Agency (NBA) is responsible for assessing the design of housing and various building systems. Housing systems are evaluated from the standpoint of materials, site preparation, fire precautions, thermal insulation, sound insulation, structural stability, chimney and flues, heat producing appliances, and probable maintenance problems. Arrangements are being made for the NBA to issue Agrément certificates in its area of responsibility.

In conclusion, the Agrément is a well-qualified evaluation. It is required by the Ministry of Public Building and Works in the fifty percent of housing in Great Britain in which that agency is involved. An Agrément certificate is not required for code approval, however, and the developer of a new product may elect to follow the procedure common in this country of obtaining acceptance by one or more of the 1400 local code jurisdictions, and then using this as a lever to develop acceptance in a wider area.

Germany

A central approval agency, Zulassung, was established in Germany prior to 1900. With the creation of the German Federation after the Second World War, the approval function was transferred to the States. However, there is cooperation among the States, and appeals may be directed to a Federal Coordinating Committee. Testing and evaluation is carried out at a number of universities; the proponent of the innovation having a choice of several specializing in a given area. As in other countries, Zulassung concerns itself with innovation, traditional materials being covered by the Deutscher Normanausschuss (DIN) specifications. For example, the Heidelberg Cement Company has a Zulassung for masonry cement, a moderately new product in Germany, while more conventional cements are covered by DIN standards. The Zulassung system also utilizes committees comprising technical experts, architects, engineers, producers, and users.

Denmark

The approval system in Denmark is operated by the Danish National Institute of Building Research. Evaluations are made in the laboratories of this organization, but tests may be carried out in an approved industrial, technical, or university laboratory. The proponents must state the intended use of the material, or system, and cite pertinent requirements in the code.

About 100 approvals are processed each year. Many of these are assessed by routine procedures and do not require development of new testing methods. The proponent pays three quarters of the expense. Approvals are denied if there is insufficient experience in product use, if the request is purely for advertising purposes, if it concerns only minor changes in an existing product, or if it is to be a one-time use. Approval is given for a stated period, but it may be renewed. There can only be one reapproval, but this may be followed by a permanent document. The latter may consist of a new type of evaluation procedure rather than a conventional standard. Another government organization, the National Test Station, works in close cooperation and is responsible for labeling products meeting Agrément requirements and conventional standards. Building inspectors are required to accept approved items.

Netherlands

The Agrément system in Holland is conducted by the Ratiobouw. The Ratiobouw has no laboratories and depends upon universities for testing. The issuance of an Agrément is by committees, to which the Ratiobouw makes its recommendations. This is in contrast to the French system where the committee makes the recommendation to the Director of C.S.T.B. At present, contractors and manufacturers are not represented on the committees, but they may be in the future. There is a separate committee for each area such as floors, ceilings, etc. There is no legal requirement for acceptance by the code officials of the assessments, but since the large cities are usually represented on the committees, acceptance is assured. The Agrément is required, however, in housing sponsored by the government, which amounts to about eighty percent of the total.

The UEAtc-Agrément Union

It will be noted from the descriptions above that the various Agrément systems have a great deal in common. This community of interest has led to the establishment of an official Union of Agrément systems. Present members are Belgium, France, Greece, Italy, the Netherlands, Portugal, Spain, and the United Kingdom. Austria and West Germany have observer status. The latter will soon become a full member. The Union issues Common Directives which establish the procedures of assessing various products and systems for example, windows. The Common Directives enable one country to use an assessment carried out in another. Thus, potential exists not only for a full national market, but also for an international one. An Agrément given in one country does not automatically insure its adoption by other member countries of the Union. Each member retains the right to decide in such matters. In accepting each other's assessment, or in using the Common Directive, a country may find it desirable or necessary to take special account of conditions peculiar to its own situation such as climate or building regulations. Under the system potential exists for countries to develop expertise in specific areas, and thereby to be in a position to serve the needs of all the members of the Union. The Union also prescribes methods for arriving at Agrément decisions including the use of technical experts to make assessments in areas where testing procedures are not available.

Summary

Certain aspects common to all of the systems should be pointed out. All are limited to evaluating the performance of innovations. Their assessment is based on stated uses or methods of application of the innovation. The need to develop new testing procedures, a cost which probably cannot be equitably assessed against the proponent of a new system, requires a substantial subsidy in many cases. Each system relies heavily on the collective advice and judgment of a group of technical experts who assist in interpreting the test results, who may participate in designing the test program, and who, most importantly, estimate from background knowledge the probable performance related to areas for which no testing methods exist. Such experts can be assembled from many sources, but it appears that organizations such as the French C.S.T.B. and the British Building Research Station offer the most concentrated, and hence readily available, sources of research knowledge to supplement that of representatives of other segments of the building industry in arriving at Agrément-type decisions. As far as can be judged, the approval systems described fill an important need in the building process and have obtained a high degree of acceptance by all segments of the building industry, even though dissent is not wholly absent. It is hoped that the study upon which this report is based will be useful in the design of a new procedure for the United States in assessing innovations.

MODULAR COORDINATION: A BASIS FOR INDUSTRIALIZATION OF THE BUILDING PROCESS

Russell W. Smith, Jr.

Building Research Division
Institute for Applied Technology
National Bureau of Standards

I am sure you are all familiar with the story of Cinderella, her beauty and talent, how she was ignored and confined to a chimney corner, and how a Godmother appeared and performed an act of magic—removed the dirt and grime, allowing Cinderella to appear as she really was, and to claim her place as princess of the land.

The building industry also has its Cinderella. This Cinderella is my subject today, modular coordination. Since 1938, its value and utility have been recognized. But it too has been ignored and confined to a chimney corner by a lack of building industry concern. The story of the building industry's Cinderella—of modular coordination—is only half finished, however. Modular coordination is still in its chimney corner, but I am confident that its Godmother has appeared, and that there is in process an act of magic which will soon release modular coordination so that it can become a princess of the building industry. The Godmother of the building industry's Cinderella is the current need to double our output of housing and substantially increase the production of other buildings, all within the next decade. The magic ingredient that will make modular coordination a princess of the building industry is the recognition by all concerned that the job probably cannot be achieved without it.

To understand why this is true, let us look at modular coordination. How is it defined, what is its function, and why is it essential to the economical production of a higher volume of housing? First, the module referred to in the term modular coordination is a unit of length as precise as the state of the art of metrology can make it. It is currently fixed, in a United States of America Standards Institute standard, at four (4) inches. This is the fundamental unit around which the dimensional coordination of the building industry has been established. Thus, the modular unit has become the basis for dimensioning in the building industry. The basic module is the "meterbar" for building, and, because it is metrology, it should be treated as a precise science of measurement on which all standards for building industry measurement should be based.

If this, then, is the meaning of modular, as used in the term "modular coordination," what is the meaning of "coordination" in the same context? To answer this we must look at the history of modular coordination. Initial work begun by the Albert Farwell Bemis Foundation was directed toward industrializing the home building process. The objective was to establish the basis for applying to building those principles of industrial efficiencies that Mr. Bemis had seen applied to other industries during the industrial revolution around the turn of this century. To establish this basis meant the development of a body of industrial standards for repetitive processes and interchangeable parts, made possible by other standards for the control of dimensions and of quality. The latter standards were, of course, based in turn on the science of metrology which controlled the preciseness of measurement, of dimension, and of quality. It is clear that Mr. Bemis saw as his objective the establishment of standards which could increase the efficiency of the manufacturing process that produces buildings; standards related to the process of manufacturing buildings, not to the result, the building itself. This is important.

A working definition of modular coordination can now be derived. It is: "A system of standards for the industrialized production of buildings based on the metrology of the module." Again, "A system of standards for the industrialized production of buildings based on the metrology of the module" keeping in mind, of course, that the module is an established unit of measure of exactly four (4) inches.

With this definition in mind, let us examine the function of modular coordination. But, before doing this let me establish a painful and very embarrassing fact. Perhaps only one segment of the building in-

dustry today can truly claim to be industrialized. If you subdivide the so-called building industry and put those who manufacture the parts and materials that are supplied to the site on one side, and the construction, or assembly, of the building itself on the other, you will see that the supplier segment is highly industrialized. Gypboard and plywood are manufactured with all the production efficiency of auto windshields. Production line efficiency in the manufacture of furnaces and air conditioners equals the efficiency found in the manufacture of their equivalents on aircraft or auto production lines.

The other segment of the industry, however, that assembles the suppliers' parts into the final product, the building, is not industrialized. For example, compare the assembly of a building to the assembly of an automobile. In the case of the automobile, the design of the final product and the design of the parts are coordinated so that manufacture of the auto is essentially an assembly process, with little or no fabrication required. In the case of the building, the design of the product and the design of the parts that comprise it are not coordinated. Fabrication or modification is required of almost every item during assembly. The fact that there is little or no true industrialization in the segment of the manufacturing process that assembles buildings from suppliers' parts is of little concern as long as the time and labor required to make things fit are available, and their use and cost are acceptable. This on-site fitting process has, of course, been traditional in the assembly segment of the building manufacturing process. Unbelievable as it may be, the simple fact is that the final assembly segment of manufacturing buildings has not yet adopted the basic industrial principles that revolutionized the mechanical industries a century ago.

The broad function of modular coordination is to make possible the introduction of basic industrial principles that will bring to building the industrial efficiencies that came to the mechanical industries 100 years ago. To understand how this can be accomplished, let us look at what happened in mechanical manufacturing. Before the nineteenth century industrial revolution, in mechanical manufacture, as in the final assembly of most buildings today, well-fitted and beautifully finished work was produced. It was produced with great skill by fitting part to part. There were no common standards controlling dimensions or fit. The need for such standards arose only when large numbers of like products were produced and the advantages of assembly from interchangeable parts, without modification at the time of assembly, became apparent.

Not surprisingly, these general principles were first applied to the manufacture of guns. This happened in France in 1776. Principles and techniques were established for interchangeability of manufactured items, including standard sizes for bores and ammunition, the fixing of tolerances of fit for components, and verification of the sizes of all parts by "go" and "no go" gauges. Eli Whitney applied similar techniques in manufacturing rifles for the U.S. about 1800, as well as in cotton gin manufacture.

But it was not until Joseph Whitworth identified them between 1840 and 1880 that the fundamental requirements for repetitive manufacture were clearly established. Essentially there were four requirements.

The first was metrology. Whitworth recognized the total dependence of mass production on common dimensional standards.

The second was the need for an accurate plane surface for reference. Of this, Whitworth said, "All excellence in workmanship depends on it, for without such a surface many component dimensions are impossible, or are difficult, to measure and there cannot be a control of warping and other distortion."

The third essential requirement for repetitive manufacture was dimensional control. Whitworth understood the requirement for measurement standards to which the dimensioning of parts could be referenced. He saw this as freeing manufacture from the need for direct part to part comparison.

The fourth and last requirement, but not the least, was standardization. Whitworth said, "The very soul of manufacture is repetition," and on this belief he based the work for which he is famous—the standardization of screw threads.

In addition to the standardization of size and shape, Whitworth advocated limited series of size gradations. This did not come about for many years. Speaking in 1856 on the subject of size gradations, he said,

"This question is also well worth the attention of our architects and builders. Suppose . . . windows and doors . . . were made only of three or four different sizes. Then we should have a manufactory start up without reference to any particular house or builder. They would be kept in stock, and made with the best machinery and contrivances . . . we should have better doors and windows at the least possible cost . . ."

Thus Whitworth not only furthered the mechanical industrial revolution, but he early saw the value of production standardization for the building industry, advocating the establishment of correct measurement and its corollary, proper gradation of sizes, as the basis for repetitive manufacture we call industrialization.

Leaving Whitworth and the establishment of the basic principles of industrialization that he pioneered, let us go on to the application of these principles in the mechanical engineering field. It may or may not be true, but there is a story about Henry Ford which sums up industrial standardization. He is supposed to have been walking through the assembly plant one day when he paused at a room where newly completed engines were being test run. He asked, "Why are you running those engines?" " 'To determine that the parts fit properly,' " was the answer. "Establish production standards so that the parts fit, and eliminate testing," Ford commanded. To bring about this change demanded a higher precision of metrology, and new standards for the dimensioning of parts, for governing fits and tolerances, and for quality control. As a result, parts were fabricated to fit a standard rather than to fit each other, and part to part fitting was virtually eliminated from the auto manufacturing industry. Parts became truly interchangeable in both assembly and replacement. Whether this happened in just this way or not, it is true that in the early 1900's, the cost of a Model T dropped to $250 from the $800 it had been 8 to 10 years before. It is significant to note that this did not require a drastic innovative change in the Model T itself.

The function of modular coordination is to provide the building industry with the same type of industrial standards now applied to the mechanical industry. This could bring about the same type of cost reduction in the final assembly process of the building industry that occurred in the case of the Model T. It will be accomplished when the design of buildings, and of their component parts, is controlled by standards of such reliability that buildings may be assembled without the modification of a single component. When we can assemble a building as we do an auto engine from random selections of interchangeable parts, without modifying any, then, and only then, can we say the industrial revolution has come to the assembly of buildings.

It might be well to mention here that achievement of the industrialization offered by modular coordination does not require factory prefabrication of buildings or of components. Quite the reverse is true, since modular coordination permits the application of production line efficiencies and economies to on-site manufacture of components and to assembly procedures, as well as to manufacture in a plant. Whichever procedure is followed, dimensional finishing will occur only once, when it is most efficient. And once a component is fabricated by fitting it to a dimensional standard, it should require no alteration. Sound standards establish ground rules for the application of industrial efficiencies to all construction regardless of whether it is conventional or innovative, on-site or in a factory. Modular coordination is truly non-discriminatory.

Initially I posed three questions concerning modular coordination. What is it, what is its function, and why is it essential to the economical production of a higher volume of housing? Two of these questions have been answered. Modular coordination has been defined as: "A system of standards for the industrialized production of buildings based on the metrology of the module, currently established in the U.S.A. at 4 inches." The function of this building industry Cinderella is to provide a princess-like rule of industrial order which will allow the assembly of buildings from compatible and interchangeable parts that require no modifications for fit during final assembly.

This brings us to the last question concerning building's Cinderella. Why is it essential that modular coordination be brought out of the chimney corner and made a building industry princess? The answer is quite simple. There is no way we can double the production of housing in the next decade, and do it economically, without increasing the productivity of the industrial system that now produces housing. If you look at the vast investment in plant and equipment, in manufacturing expertise, in know-how, distribution, warehousing systems, expertise of the design professions, skills, and trades, and comprehensive managerial competence, you will see that this vast industrial capability to produce housing is to the housing produced as that part of the iceberg below the water is to the part above.

Barring an end to the Viet Nam war, and the development of some system whereby the industrial base that now produces armaments could produce acceptable housing, it is doubtful whether we could create in ten years a new industrial capability equal to, and replacing, the existing industrial base that now produces U.S. housing. A contribution could

come from some totally new innovative industrial system. But, if we are to solve this problem and provide adequate housing, we must solve it as other nations faced with the same problem have solved it—by concentrating our efforts on increasing the productivity of the existing industrial system that produces most of our housing. Such an increase in productivity means not only more units produced, but also a lower cost per unit. It is an economic necessity to utilize to the fullest extent possible the vast industrial capacity this nation has created within its building industry.

This is the magic that is occurring which, I am certain, makes the recognition and use of modular coordination inevitable. The time has come to dust off the building industry's Cinderella, to present her to public view, and let her bring about the increased productivity of which our building industry is potentially capable. While we are looking for new and better systems, however, let us not fail to "systematize" the very good industrial base we already have. To overlook or neglect this vast resource could be tragic.

Quite often at this point in a presentation of this type, the speaker comes to an embarrassing moment of truth. After dwelling at great length on the importance of his subject, he may face the reality that little or nothing is being done to implement his views. Fortunately for me as a speaker, and for the building industry, this is not true of modular coordination. The National Bureau of Standards is sponsoring within the United States of America Standards Institute an activity which is moving ahead rapidly to accomplish the objectives about which I have been talking. This activity is the responsibility of the USASI Standards Committee A62, "Pre-Coordination of Building Components and Systems." In less than two years it has established itself as the recognized central forum for developing standards for dimensional and functional coordination of building components and systems. To do this, A62 has had to develop an effective organization for achieving its objectives. This organization now includes over 30 trade associations, 20 major corporations and 5 federal agencies, and embraces most of the major interests in the diverse building industry. The effective government-industry partnership in A62 assures that the standards it is producing will be useful and applicable to all phases of an exceedingly practical industry.

In the same time span, A62 has made other major strides. First, it has developed the procedures under which it is now operating. I would like to stress the "now operating," and qualify it by adding, "very effectively." The work of standards-writing technical committees is guided by subcommittees which concern themselves solely with determining the scope of standards needed, and assigning priorities according to importance, so that the efforts of the committee will not be wasted and each effort will build upon the last. In A62 there are now four of these programming and planning subcommittees. They deal with:

1. a basis for dimensional coordination;
2. a basis for functional coordination;
3. a basis for communication coordination; and,
4. the application of these three coordination bases to manufacture, design, and erection procedure.

At the request of USASI, A62 accepted responsibility for U.S. participation in the modular standards activities of the International Standards Organization (ISO) and the Pan American Standards Commission (COPANT). This means that the A62 Sectional Committee has agreed to establish the U.S. position on standards under consideration by both these organizations.

Acceptance of ISO and COPANT responsibility opened liaison between A62 and the work being done on component coordination and modular coordination throughout the world. This ISO contact has made possible working relations with the leaders of modular coordination in most of the major countries of the world and has opened the way for an exchange of information. It has also brought to our attention several standards, and many working documents, which were not otherwise available, and which have direct application to our work.

Perhaps the most important ISO activity concerns the British. They were recently named as the secretariat of a new ISO subcommittee (SC5) which is charged with developing an orderly program of work, and a priority of projects to guide the ISO international modular effort. This corresponds very closely to the efforts of the A62 programming and planning subcommittees, and A62 participation on the new SC5 has been arranged so that we may have this valuable input to our work. It should be particularly valuable since the British are combining their conversion of the building industry to metric and modular coordination into a single package. Through this combination, the increased produc-

tivity resulting from the modular technique offsets the cost of converting from inch to metric measures. Canada also is using this work as a basis for pushing modular coordination.

As for actual accomplishments to date, a standard establishing a systems module and series of compatible component dimensions for horizontal dimensioning has been approved by the A62 committee and accepted by the Construction Standards Board of USASI. It is being published by USASI as USA Standard A62.5, "Basis for the Horizontal Dimensioning of Coordinated Building Components and Systems." It will be available from USASI as soon as printing is completed. The technical subcommittee that developed this standard was chaired by W. Burr Bennett of the Portland Cement Association. Other members included:

H. F. Hann, Sears Roebuck and Co.
G. Hanson, Sallada and Hanson
D. E. Morgenroth, Owens Corning Fiberglas
G. J. Murray, American Iron and Steel Institute
L. Pearlmutter, Prestressed Concrete of Colorado, Inc.
W. K. Platt, American Telephone and Telegraph Co.
J. W. Glaser, The E. F. Hauserman Co.
M. K. Snyder, Butler Manufacturing Co.

I think that the work this subcommittee did in establishing this first A62 standard was more than just writing an American standard. This standard establishes the basis for dimensional coordination in the U.S., and can be thought of in the same light as you think of the alphabet, the meter, etc. Many, many standards for many, many years will be based on it and it will be the keystone for future dimensional coordination in the building industry. I feel that both Burr Bennett and Jack Gaston of Armstrong Cork Co., chairman of A62, have done a great job in leading the committee effort and bringing this standard to fruition.

Another subcommittee, chaired by Jim Parker of General Services Administration, is far along in drafting an equivalent standard for vertical dimensioning.

Other subcommittees are working on standards establishing:

(1) a basis for functional compatibility and interchangeability;
(2) basic coordination relationships and systems;
(3) definition of terms; and,
(4) adaptation of modular drafting for computer usage.

In summary, Committee A62 has established itself as a viable organization, has become operational, and is now a significant national force, developing fundamental standards leading to a rational industrialized building technology. If support of this cooperative and voluntary government-industry effort continues to grow at the rate it has in the past two years, it will do the job I have outlined, and do it well. It will also do it soon. The support of everyone concerned is earnestly and urgently solicited.

SESSION III. SOME ASPECTS OF LOW-COST HOUSING

J. O. Bryson, Chairman

332-247 O - 69 - 4

GOALS AND INTERGOVERNMENTAL COOPERATION IN LOW-COST HOUSING

B. T. Craun [1]

Department of Housing and Urban Development

The subject I'm speaking on today deals with the cooperation of the Department of Housing and Urban Development with other government and non-government organizations in bringing new technology to housing. Mr. Bryson, the moderator of this session, was an important link in some of the work that was conducted here at the National Bureau of Standards which I will discuss.

The national housing goal has been established at 26 million new units during the next ten years. This is approximately twice the present national rate of housing construction. Of the 26 million units, 6 million are to be constructed specifically for the lower income families. This 6 million units represents a truly major increase for the present HUD supported rate of construction. Presently, Housing Assistance Administration, one of the sub-agencies within the department, is constructing or causing to be constructed, roughly 50,000 units a year. This is up over what it was several years ago. However, you can see that jumping the rate of 50,000 to 600,000 a year is a very significant increase.

We have many many problems in trying to accomplish our goal of obtaining these 600,000 units. There are really four items which we don't feel that we really know. First of all, we really don't know how to build housing for lower income families. By this I mean, there are many things that are important to the lower income people which we as middle income, middle class people, fail to recognize. Let me give you an example. In one project that we undertook in an isolated area, Rosebud Reservation in South Dakota, we found that it was far more important to provide the house with a wood burning or oil burning stove than a central gas furnace, which used butane. It was more important because this matched the income pattern of the people. They could always obtain 50 cents or a dollar's worth of coal oil or wood to keep warm in the winter time, but they could not fill a butane tank with butane. They just didn't have the money. So this was important to the people, that they be able to visualize, to understand how they can operate their housing. There is also the matter of reduction in cost. We find that we can build housing that meets the needs of these people cheaper, than what we can build, if we follow the standards that we have normally set.

The second thing we don't know is how to rapidly and effectively produce housing, that is, produce quantities of housing at the lowest cost. Thirdly, we don't know how to pay for this housing. We know that there are many mechanisms, such as government subsidies, that can be tried, but how and where these should be tried, we still don't know. And fourth, we don't really know how to effectively manage the housing after it is built. We do know that many projects fail because of poor management. We have numerous examples of this and we feel that other projects are highly successful because they involve the people themselves in the management. This is an area in which considerable cost savings can be effected. All of these we are looking into, one way or another.

To accomplish this goal of six million units for the lower income families at today's prices and using today's technologies, will cost something in excess of $100,000,000. Any reduction in the cost can serve three important and valuable functions: (1) reduce the cost to the government, (2) potentially allow more families to be housed more rapidly, and (3) allow more lower income families to obtain self-sufficiency and self-respect by paying for their housing. We think these are all very important aspects.

Accordingly the government is trying to find ways of providing housing cheaper. Congress has given HUD both the authorization and appropriations to encourage new and improved methods of housing lower income families, thus, allowing greater freedom in innovation and experimentation. I must point out that by definition, the rapid construction of attractive and low cost housing for lower income families will require a great deal of innovation in all activities of the housing industry. We have the programs for conducting experiments and building experimental houses. In fact, one of our programs, an insurance program designed for ex-

[1] Mr. Craun died shortly after the Conference; the Editors have prepared his paper for publication.

perimental housing, assures that the home owner, if it's an individual house, or the project, will not suffer by virtue of the experiment. We will repair damage and so forth due to the experiment for the life of the mortgage, up to forty years.

We have been working with numerous cities and in all cases we find that the city building code is designed to protect the life and safety of the occupants of the building. It is not designed to permit experimentation, and the enforcing agency, the building department, is only warranted in issuing a building permit when and if they can be assured that the building is safe. Over a year ago we undertook an experiment with the Roman Catholic archdiocese of the city of Detroit to try to test a new technology in Detroit. This particular experiment had two goals: one was to involve the local low income people in the actual design of the housing which they would receive, and the second was to test the cost effectiveness of a new construction system, the Neal Mitchell system. Mr. Mitchell will talk about both of these items, I'm sure. We were proceeding along well until we found out that the new material, which was a cellular concrete, did not meet the provisions of the building code of the city of Detroit. As a consequence the building permit could not be issued. The city buildings department could not be assured that the use of cellular concrete as a structural material was valid. As a consequence, we had numerous discussions with the people in the city of Detroit and they organized a local board of professional engineers to look into the matter of cellular concrete and make recommendations. The Government in turn, called upon Mr. Soteriades of the National Academy of Sciences, Mr. Heightman of the Corps of Engineers and Dr. Pfrang of the National Bureau of Standards to review the plans, specifications and so forth, to try to assure all of us that this building was safe. I want to assure you at this time that HUD does not intend to experiment with structures which will be unsafe or which will cause any risk to the occupants.

The group of three gentlemen, the experts that I mentioned, proceeded to get together with the local group of engineers from the city of Detroit and work up a test program, which if successful, would produce conclusive results on the adequacy of the structure. Accordingly, HUD undertook a contract with the National Bureau of Standards and a full-scale laboratory test was made. I believe this was one of the first full-scale laboratory tests of a multi-family housing system performed in this country. I know there's been other full scale testing of housing, but I think this is one of the more pertinent firsts in this country.

We believed that once the National Bureau of Standards performed the test, the results would then have national applicability. In other words, any city throughout the country, would accept our great National Bureau of Standards' work. As a consequence of the test results which Dr. Pfrang will discuss in more detail, the city of Detroit found that they could accept the structure and have done so and have issued building permits.

I had hoped that by the time I appeared before you today, I'd be able to tell you that the buildings are under construction. They are not yet under construction. You people that are in the construction business know all the involvements of trying to get from the building permit to the ground breaking. However, I will say that our present schedule, which looks very realistic, calls for the construction to start on October 15. There will be a ground breaking ceremony on October 8 and utilities will be installed about that time.

I need to point out that this, while it appears to be relatively simple, establishes a first for HUD and for the National Bureau of Standards and for the National Academy of Sciences. We have all worked together and have now found a method for working with the cities which we believe can assure them of the adequacy of new products or new systems.

Essentially, I must say, we are interested in the new systems approach and we are now prepared to go even further with other systems as the need arises. I've had numerous discussions with the people from the city building department and they seem very well pleased with the fine cooperation that exists between the government, that is the National Bureau of Standards, the National Academy of Sciences, the Corps of Engineers, and ourselves and themselves and their committee of local professional engineers. We believe that we have established a method whereby we can work successfully with the cities.

DESIGN ASPECTS OF A LOW-COST HOUSING SYSTEM

N. B. Mitchell

Neal Mitchell Associates, Inc.
149 Putnam Avenue
Cambridge, Massachusetts

Abstract*

The morphology of a systems approach to the design of low-cost housing is described. Design should respond to the proper interfacing of the various components and optimization of the components with respect to the total system. The development of appropriate hardware is programmed as well as the design process network schedule and the construction process network schedule.

To satisfy user requirements consideration is given to space requirements, deterioration, flexibility including opportunity for expansion, and capability of individual expression to provide the user with an identity of their own. The user must be given something to look forward to, a piece of the action on a scale that does not destroy his dignity.

Non-verbal people can communicate if the proper method of communication is selected. People were allowed to arrange furniture for the various rooms in open spaces uninhibited by walls. A surprising result of this activity was that the room sizes required for the furniture arrangements were smaller than rooms originally rejected by the people as being too small.

To aid in design an interaction matrix involving 36,000 points of contact was established. Examples of the items in the matrix are manufacturability, productivility, livability, rooms interrelation, relation of one apartment to another, relation of a group of apartments to the urban sector, etc.

User requirements were developed from the social standpoint to aid in building an environment where reasonable living standards could exist. However, it is essential also to consider cost and this involves initial cost, maintenance cost, rehabilitation cost, component obsolescence, interface obsolescence, depreciation rates, social and economic values, etc.

The basic design made the wall system linear so that parts could be shipped like Lincoln Logs and walls plugged in or out. The system would alleviate the cost-bind by permitting the development of a market for used components.

By providing for vertical as well as horizontal expansion, a variety of housing types is possible. Designing a system that is easier to expand in certain directions permits some control over the growth of a community by orientation of the interior module.

A few of the many things to be considered in predetermining what should be developed are trade-offs, interactions, cost-savings, exterior finishes, architectural and social aspects, and interplay of spaces. Other considerations are how to build alternative sets or units—single family to three-story housing—with a fixed system, how to give people opportunity to make choices—a front porch if they want to see the action on the street or a private urban space in back if they want isolation, and how to develop a heating system that can be expanded easily to include humidity control, air conditioning or electrostatic precipitation at a later date.

To meet the housing needs of the country it is necessary to sophisticate the technique, the scheduling, the materials flow, research and development process for developing new materials, the performance requirements and reduce the waste time in construction.

The fundamental concept is to build a housing system rather than a structural system.

*Abstract prepared by the editors. The speaker did not submit a manuscript.

PERFORMANCE TESTING OF A LOW-COST HOUSING SYSTEM

E.O. Pfrang

Building Research Division
Institute for Applied Technology
National Bureau of Standards

As the title of this talk indicates, I will be discussing the full-scale performance testing of the Neal Mitchell Housing System mentioned in the previous talk. However, rather than interpreting my remarks in terms of this particular system I would prefer that you view them in terms of the general problem of the performance evaluation of innovative building systems. It is easier to speak in terms of a specific example to demonstrate what we mean by performance evaluation.

Full-scale performance testing is really nothing new. The Europeans in their bridge construction have for years insisted on a full-scale performance test before putting their bridges into service. Many of you have undoubtedly seen photographs of lines of heavily loaded trucks on these bridges. However, this concept is relatively new in the area of housing. We are, in fact, just beginning to apply it. The Europeans use the performance test as an acceptance test. The thing that we are proposing here is quite different. What we have in mind is the evaluation through performance testing of a prototype which is in itself representative of a great number of building units.

Before going too deeply into this talk, I want to caution that performance testing is by no means a panacea. We cannot at this point of time fully evaluate a building system purely on the basis of a test. We must supplement the information by applying judgment. It might be well for us to reflect upon the traditional method of evaluating building systems from the structural standpoint by analysis and computations. We might say that we test the structure numerically. However, even here we supplement these numbers with judgment. We apply judgment in the interpretation of the computations. No one would be rash enough to say that computations without judgment could be used as a basis for the evaluation of the proposed building structure. Just as we use judgment in our traditional methods, we must also apply judgment in the interpretation of the results of performance tests. The judgment which is necessary for the evaluation of building systems subjected to performance testing must be provided by a person with a high degree of professional skill and an understanding of the behavior of structural systems.

Figure 1 shows a model of the Neal Mitchell Housing System as proposed for erection in Detroit. Before the Commissioner of Building and Safety of the city of Detroit was willing to accept this system he had to be convinced of its structural adequacy. Essentially, he was saying, "Prove this system mathematically." He was asking that this building be proven in a manner similar to that which was being used for all of the other buildings proposed for erection in Detroit. However, as you have already gathered from Mr. Mitchell's remarks in the preceding paper, this was a highly innovative system, which had a number of departures from existing practice and from existing codes. It would have been either impossible or at any rate extremely difficult to mathematically prove the system. Mr. Mitchell did submit computations concerning the system. These computations were, as far as the state of the art permitted, quite reasonable. However, there were a number of details—such as the properties of the cellular concrete, the interconnection of components, the methods used in obtaining continuity, the strength of the walls, and other details which were in question. Negotiations

FIGURE 1. Model of the proposed housing system.

between the city of Detroit Archdiocese, which was the sponsor for this particular housing project, had gone on for over a year with no real headway being made.

The Department of Housing and Urban Development, which was providing funding for this project, had been following the difficulty in Detroit with considerable interest. After it became apparent that a reconciliation between the two sides by traditional procedures was not possible, HUD decided to try a somewhat different course. It first appointed an advisory panel consisting of The National Academy of Sciences, the Army Corps of Engineers and the National Bureau of Standards. It charged this panel with investigating the structural adequacy of the system proposed for erection in Detroit. The panel reviewed in considerable detail the plans, the computations and the specifications of the system along with a number of other documents. Based upon this detailed consideration of the proposed system, the panel advised HUD that, in its opinion, the system was probably quite safe; but that there remained a sufficient number of questions to make some type of performance testing prior to construction mandatory. The panel pointed out to HUD that full-scale field testing was one possible solution to this problem. The recommendations was for full-scale laboratory testing of a module of the proposed building system. The choice of laboratory testing as opposed to field testing was based on the fact that HUD was particularly anxious to make housing available to the people of Detroit and time was of major importance. The laboratory test made it possible to determine the behavior of the building system in a minimum of time.

Figure 2 shows the structural components which were used in the building system. These, however, are not the whole structure; the structure consists of these precast components, along with the in-filling gypsum walls which are an integral part of the overall system. So, in our laboratory we erected, not only the precast components, but also the in-filling system.

The question which was raised was: Is the system structurally adequate? It had new materials; it used different construction techniques; it had innovations; and it definitely had code departures. The ACI Code, for example, has minimum column sizes which are far in excess of the column sizes which were used in the Mitchell System. The interconnection of the cast-in-place slab, which you will

FIGURE 2. Assembled precast structural components.

see shortly, was a departure from the allowable code spacing of shear connectors. The inserts were wider spaced and they were not of a type that is generally considered to be covered by the present codes.

What are the structural performance criteria upon which one judges a system? One is safety; the other is serviceability. By safety we mean reliability against collapse; that is, against killing someone. In the case of serviceability, we are concerned with the static stiffness of the structure, or does it deflect too much as you walk across it? What is its dynamic response? When you walk across it do you get a feeling of motion? And finally by serviceability we also mean freedom from distress. As this building system is in service, do you have cracking?; do you have evident signs that something is amiss, spalling, etc.?

From the standpoint of structural safety, we tried to set down what we felt were some detailed performance requirements, the state of the art in the area of performance requirements is not perfect by any means. What we did was to look at existing building codes, at existing practice, and we asked

ourselves what are we doing today with our present conventional buildings; what are we asking these buildings to do? We have had experience with these; and from this experience can we come up with a set of requirements that we can set down and use as a basis for evaluation?

Table 1 is an abbreviated list of the performance requirements that were set down: First, the structure had to have a certain safety with respect to floor loads. The particular values that are listed, 1.5 dead plus 1.8 live, are fairly well recognized in existing codes. These are not the exact numbers but generally they are in this range. We have had the experience which shows us that if we design a system which will have this sort of capacity it will behave reasonably well. Again, with respect to wind load, we do not have any good performance requirements related to wind load; but most designers have found that if they design with 0.9 dead and 1.1 wind load they will have a structure which will perform reasonably well. The values for wind loads were magnified by 25% to account for possible variations in the strength of the test structure.

Table 2 gives an abbreviated list of performance requirements related to serviceability. This list doesn't cover all of the things which were considered, but it does indicate some of the items which we were looking at. For floor loads, we have found that, if we design a floor system so that it does not deflect more than 1/360 of the span we end up with a reasonably satisfactory structure. However, this $\ell/360$ takes into account just the bare structure without the stiffening effect of non-structural elements. We had to be a little more conservative when we started dealing with systems, so we compromised on the $\ell/480$ for the deflection requirements for the floor under one dead and one live load. Another requirement that we usually put on a system when it is field tested is recovery. We usually require that there be reasonable recovery and therefore felt that 75 percent recovery of the deflectance was a reasonable value to expect for a system.

Finally, it is necessary to set some criterion with respect to wind load deflection. There is not any valid criterion available to us for judging a low-rise

Performance Requirements

TABLE I. *Structural Safety*

Floor Loads	1.25 (1.5D + 1.8L)
Wind Loads	0.9D + (1.25) · 1.1H

TABLE II. *Structural Serviceability*

Floor Loads at D+L	$dv \leq \frac{\ell}{480}$
Wind Loads at 0.9D + 1.1L	$d_h \leq \frac{h}{500}$

Symbols: Table 1 and 2

D Service Dead Load (40 psf = 1915 newton/meter^2)
L Service Live Load (80 psf = 3830 newton/meter^2)
H Service Wind Load (20 psf = 958 newton/meter^2)
ℓ Length of Member
h Height Above Grade (Ground Level Outside of Building)
d_v Vertical Deflection
d_h Horizontal Deflection (drift)

building such as the Phoenix Project in Detroit which is only going to be three stories. So we talked to a number of consultants who have been daring in their designs and they indicated to us, that in high rise buildings, when they design for story drift in excess of approximately h/500 they get complaints (h/500 is a measure of story drift where h is the story height). People notice that their martinis slosh around in the glass and they get visible tides in the bathtub. These designers then have set a rule of thumb for high-rise buildings by which they limit the story drift to h/500. We did not have anything better to use for the evaluation of this particular system. So we set h/500 as our criterion. I guess in a way this paper is sort of a plea for additional research which will lead to a better set of performance criteria. I am giving to you now the performance criteria which we used in evaluating this system. These are not what we should be using; they are just the best that we have available today within the present state of the art.

Figure 3 shows the components arriving here at the Bureau grounds, ready for erection; the precast channel elements down below, the precast structural elements piled on top.

Figure 4 shows the structural model that we tested. I call this a model because, even though it's full-scale, we were still modeling the overall performance of the building, as it would be erected in the field. The model was one story in height, two

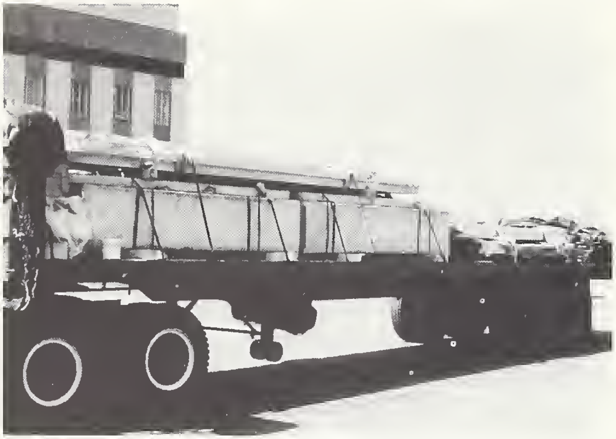


FIGURE 3. Components for test structure.

bays in width and one bay in depth. This represents a typical element from a three-story building. This would be repeated several times; three times vertically in a three-story building and a minimum of two times in depth in a typical building. The reason that we selected this element was that it represented a typical lower story module of the system to be erected in Detroit. We wanted to have a representative section of the structure and to have in it one beam unsupported by any of the in-filled walls because this was judged to be possibly the most critical part of the entire structure.

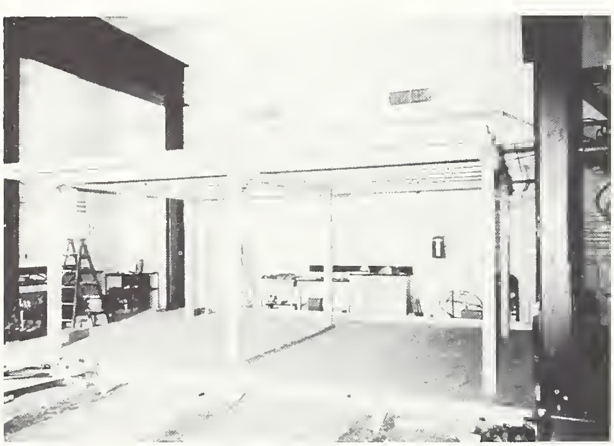


FIGURE 4. Test structure before installation of walls.

In Figure 5 we see the completed full-scale test model with the in-fill walls in place. The scaffolding that you see on the inside was merely a safety precaution because we had to get into the building during the testing.

Figure 6 shows the building after erection of the test frame. Note the wide flange steel beams which were used to provide reaction against the test struc-

FIGURE 5. Completed test structure.

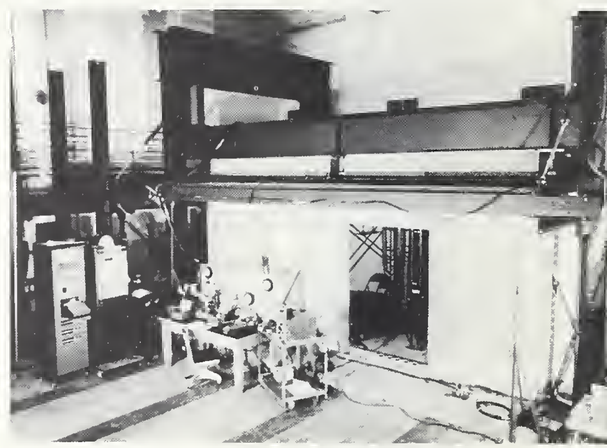


FIGURE 6. Test structure with test frame installed.

ture. The members in front of the test structure provide reaction for wind loads.

A somewhat better view is obtained in Figure 7. We loaded this test structure in the following manner: wooden boxes were used to provide the reaction against the floor load, which was applied by plastic air bags placed between the wooden boxes and the structure. By inflating these we could provide a very uniform distributed floor load on top of the structure. Note the vertical jacks which simulated the loads which were coming from the two stories above, to simulate completely the behavior of a three-story building. Horizontal rams were used to simulate the wind load. These rams provided not only the wind load that would be applied to the lower story, but all the wind loads that would be accumulated and brought on down from the upper stories.

The instrumentation which was installed on the structure is shown in Figure 8. As a laboratory test, we had the liberty of installing a great deal more in-

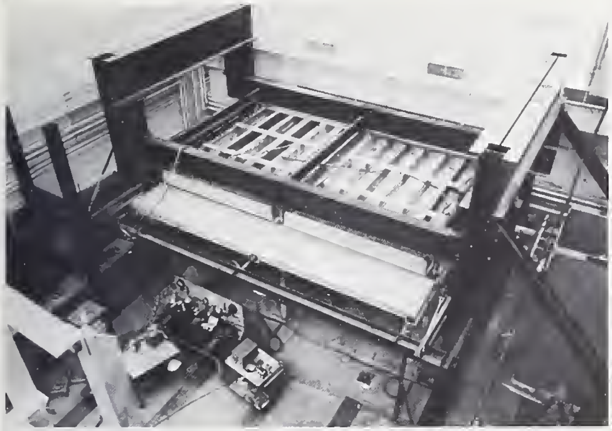


FIGURE 7. Top view of test assembly.

strumentation than would ever be possible in the field. We were able to install a total of 130 automatic recording instruments on this structure—a number that would not necessarily be impossible, but prohibitively expensive and difficult to install in the field.

Figure 9 shows a test in progress. Note the automatic data acquisition equipment which made the whole test sequence very rapid. We were able to carry out all the tests on the system in a total of six days.

Now, getting back to the requirements. We set a requirement that, under a floor load of one dead and one live the vertical deflection could not exceed the span divided by 480. And, we had to have a 75 percent recovery.

We see this performance requirement graphically presented in Figure 10. The ordinate is Floor Load in pounds per square foot; the abscissa is vertical deflection. Note that we have a broken scale.

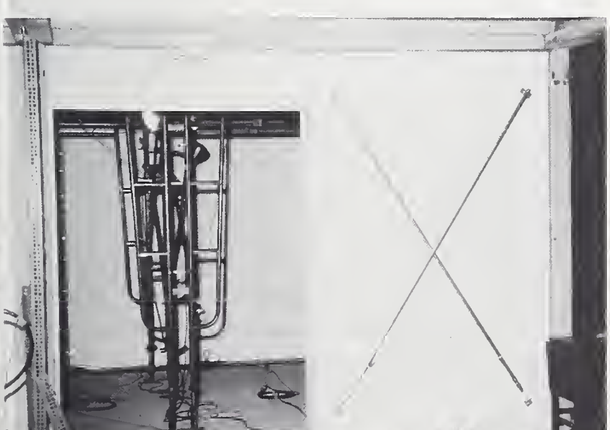


FIGURE 8. Partial view of instrumentation on test structure.

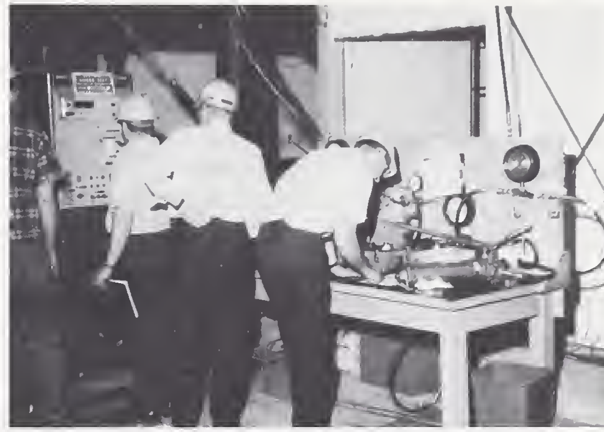


FIGURE 9. Test in progress.

In Figure 10 we see then the performance of the actual building. The first part of the response curve is deflection under the application of the vertical loads from the two stories above. These are the column loads coming down from above, and we did experience some column shortening. Actually, this deflection should be excluded from our performance requirement, because, normally, when we set up a requirement of $\ell/480$, we are concerned about the deflection of the floor itself. Beyond this initial stage the structure responded linearly. We had other performance requirements, as I have mentioned earlier, which required that we go to considerable higher loads during this test. The load was held for 24 hours, and then unloaded. After unloading the structure was allowed to sit for another 24 hours. We got a considerable amount of recovery. Note that the structure more than

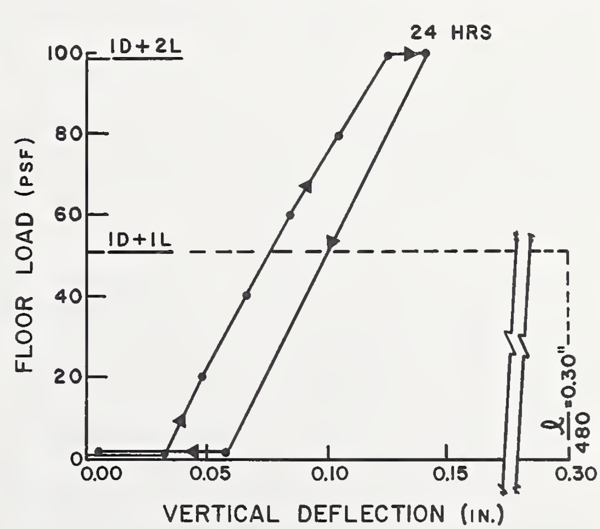


FIGURE 10. Performance of test structure under vertical load.

satisfied the performance criterion. It deflected about eight-hundredths of an inch, whereas thirty-hundredths of an inch would have been acceptable.

The next serviceability requirement which I would like to discuss concerned the response of the system to full wind at 0.9 dead load. You may well ask, "Why do you use 0.9 dead, rather than full dead?" The reason for this is that it has been our experience with building systems that they deflect more under small dead loads than they do under higher. The smaller the vertical loading usually the larger the lateral deflection, because the vertical loading tends to stabilize the system. Then, why the 0.9? Well, it is conceivable that you might have as much as 10 percent of the design dead load missing from the structure. This is quite possible even in the Mitchell System, where a part of this dead load is made up of partitions that will not always be installed, or floor coverings not always in place. Thus, our requirement was for a story drift (story drift is described as the horizontal movement of one floor relative to the other) equal to or less than one five-hundredth of the height of the story. This performance requirement is shown graphically in Figure 11. Note the response of the test structure. It sustained a considerably higher load level than required and recovered very well. The structure was well on the safe side of its allowable performance.

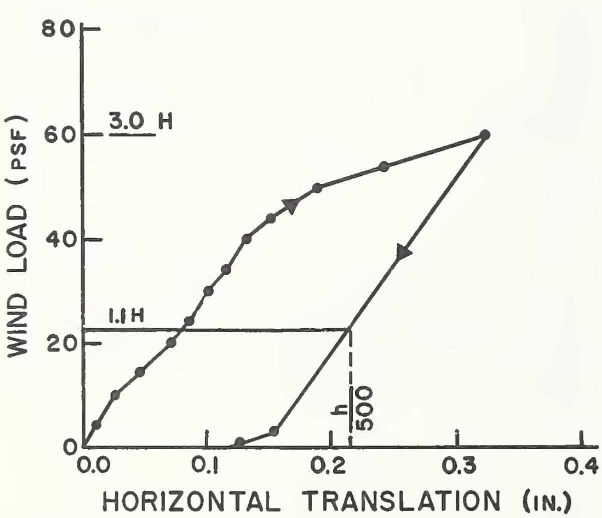


FIGURE 11. Performance of test structure under wind load.

Now, going on to the structural safety requirements (see Figure 12): for floor loads the structure was required to resist an ultimate load of 145 psf, derived from the performance requirements for structural safety, shown in Table I. This was in our

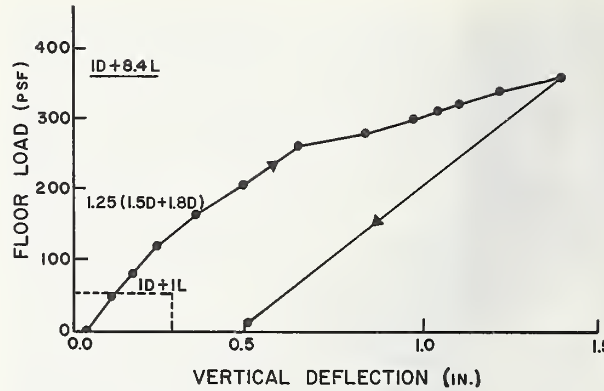


FIGURE 12. Ultimate strength of test structure under vertical load.

judgment the best estimate of the maximum possible load which such a system should be expected to resist. In reality this is a very stiff requirement in that it is equivalent to 240 normal weight people in the 12×20 foot livingroom of this building. Although this may be far too high, we just do not have the necessary basis for sharpening up these requirements at this time.

The requirement, then, was that the floor must carry about 145 pounds per square foot. Actually, we loaded the floor up to 360 pounds per square foot and the structure did not fail. At this point our loading system reached the limit of its capacity so we had to discontinue the test. At this extreme level of loading the structure was still in surprisingly good condition and showed reasonably good recovery upon removal of the load. Let me describe to you what the structure looked like at this extreme loading. There was a fair amount of cracking in some of the beams; there was no distress in the columns; and there was no distress in any of the partition walls. The structure, undoubtedly, could have carried a fair increment above this load.

Another strength related performance requirement which was mentioned earlier is resistance to wind. Figure 13 shows the results of this test. This criterion required that the system not collapse at a load of 0.9 dead plus 1.4 wind.

The structure was capable of resisting a load of 3 H or 60 pounds per square foot—three times the design wind load. As was the case for the floor load this test was also discontinued before failure was reached. A simple check of statics on the structure indicated that it was reaching the point where it was about ready to roll over. If we had loaded it up to about 80 pounds per square foot it would have simply turned over as a box since it would not have

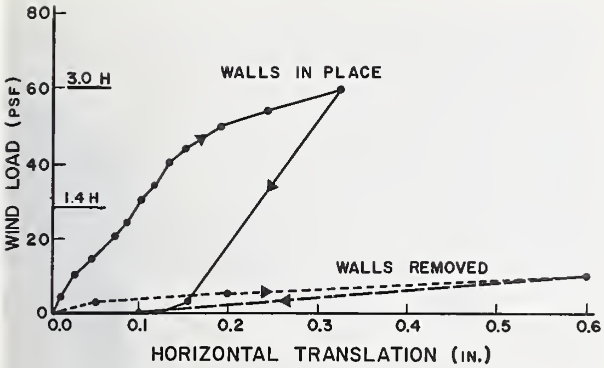


FIGURE 13. Ultimate strength of test structure under wind load.

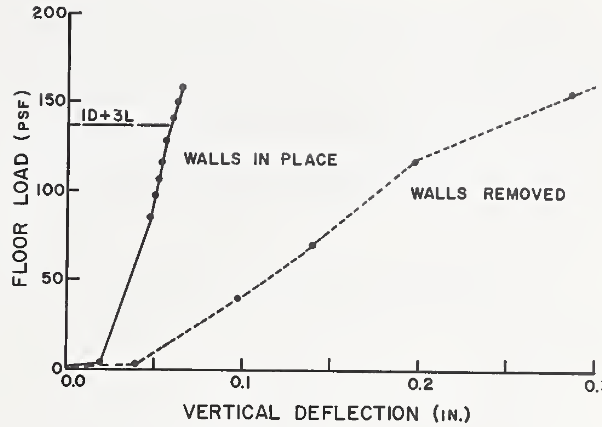


FIGURE 14. Effect of walls on structural response to vertical loads.

had enough vertical load to resist more wind. The structure was not held down in any way. The system certainly had adequate capacity with respect to wind load.

One of the things that we gained from this program of tests was an appreciation for the difference between system behavior and behavior of the "structural" portion of the building system. We ran most of our tests on the total system. These were the first tests which were run. After these were executed we removed the walls to see what would happen to the building without its walls.

Figure 14 shows a plot of floor load versus vertical deflection for the mid-span of the central main beam in the structure, both for the total system and also for the system with its walls removed. The removal of the walls dramatically altered the performance of the system. Even though the walls were not under the beam in question the effective stiffness was changed by a factor of approximately three. What happens in these systems is that, as you stiffen up any part, it starts carrying more load, the load being carried by the stiffer parts. This beam was not experiencing anywhere near the load that a simple straight forward analysis would have indicated.

What about the influence of the walls with respect to wind load? Figure 13 shows this aspect of the response of the structure. With walls in place the system was perfectly satisfactory with respect to the performance requirements that had been set for evaluatimg it. However, when the walls were removed we got a dramatic change in the performance, because these walls were carrying the major part of the racking loads that had to be resisted by the structure. As a result of this particular test it has been decided to add a note to the record drawings against the possibility of removal of walls without the provision of adequate temporary bracing. The Mitchell System was designed in such a way that it took advantage of the presence of the walls. Therefore, these are an integral part of the overall structure and it would be a mistake to permit the removal of all interior walls at any one time.

The results which I have reported thus far are concerned with the system as it was actually erected in the laboratory. There were some differences between this laboratory model and the original drawings pertaining to the system. The concrete which was used was of a higher strength and was also somewhat more dense than the concrete originally intended.

The erection of the test structure and all of the testing reported upon here were all accomplished in a period of five weeks from the arrival of the components at the laboratory. Another three weeks were required for the completion of the report which was submitted to HUD, giving the evaluation of this system.

Full-scale tests of this type are fine, however, there is a limit to what you can do with full-scale testing. You cannot build a full-scale structure to test out all of the things you might like to investigate. Your judgment would tell you that there are other things you ought to be looking at—for example, the long-term behavior of the columns in this building under load. Therefore, we proposed and carried out a set of two column tests which are still under way, in which the columns are being subjected to a continuous load of one dead plus one live. These are designed to see if there is any possibility that creep buckling could take place over a long period of time. In addition to this, we were very much concerned with the interconnection used to join the precast elements to the cast-in-place

slabs. Therefore, we proposed that a series of cyclic load tests be carried out. We had the choice of recommending a full-scale long-term test on the structure. However, we felt that this test would be prohibitively expensive. We also had the choice of recommending that a full-scale cyclic test be carried out to see how the connectors would behave under repeated load.

In our judgment, it seemed that this was the type of information that could best be gained from component tests. Thus, we proceeded with these component tests.

In Figure 15 we see one of these component tests in progress. This test specimen represents the center precast beam along with a portion of the cast-in-place topping slab which is placed on top of it. These are interconnected by a number of connectors, similar to those which were proposed for the construction in Detroit. The component requirement, which was set for this test, required the component to sustain one thousand repetitions of loading between one dead load and one dead plus one live, without showing signs of distress.

Figure 16 shows the results of the first test. These are the results on a beam, similar to that which was proposed for use in the construction in

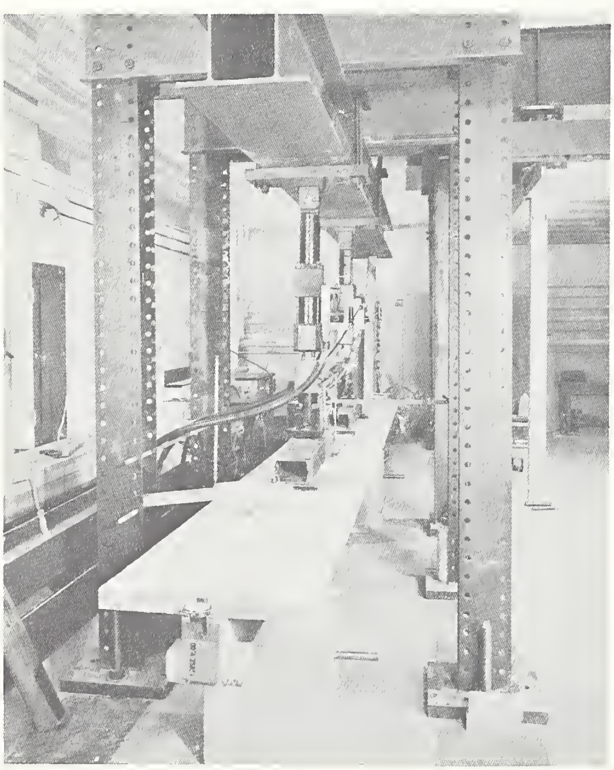


Figure 15. Component test in progress.

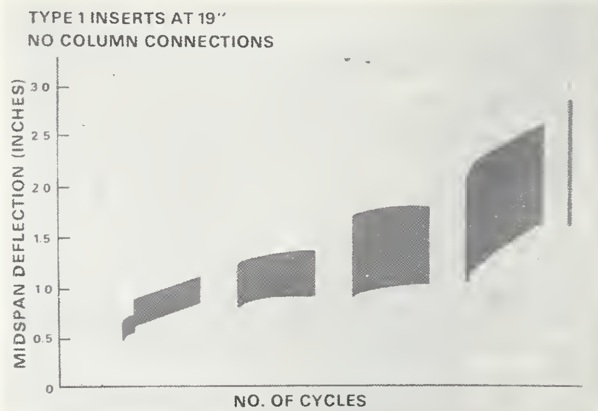


Figure 16. Component test on floor beam under cyclic loading.

Detroit. What I have plotted here is the mid-span deflection of the beam in inches, versus the number of cycles. The performance criterion which was set requires that this beam must withstand one thousand repetitions of loading from one dead to one dead plus one live, without experiencing any deterioration or slippage. We found in this test that we had a slip which occurred during the application of the first cycle of loading. This occurred at a load of approximately one dead plus one half live, but a similar slip did not occur in the total system test. Our question then was, Why didn't this occur in the total system test? Well, we had selected a component for this test that appeared to be representative of the real system; but we had never attributed any shear capacity to the column connection, which is present on all these beams. It turns out that in the real structure where you test the system you get this type of column connection; and that it apparently makes the big difference in behavior. When we went back and retested, this time with a column connection using the same type of insert, we got satisfactory behavior. The beam went through a thousand cycles at one dead plus one live load and slipped when the load was increased to one dead plus one and a half live. Thus, it was this column connection which apparently made the difference. This is one of the traps you can fall into with component testing. You single out what you think is a representative portion of the building, but it does not take into account the very complex interaction that is in existence in the total system.

We next tested a somewhat closer spacing for these connectors, using nine and a half as opposed to the nineteen inch spacing which was used in the earlier tests. We had better slip resistance under

cyclic loading, and our recommendation was that the closer spacing be used for these shear connectors.

It is interesting that the total cost for this performance evaluation was $40,000. This included the erection of the test structure, its testing, the development of performance criteria, and the evaluation of the system. Total elapsed time was eight weeks. Thus, it can be seen that laboratory performance evaluation of building systems is both an expeditious and economical vehicle for assessing the adequacy of innovative building systems. On the basis of the laboratory investigation, which I have reported upon, the city of Detroit was able to issue a building permit. The construction is now underway.

SESSION IV. PERFORMANCE TESTING OF BUILDING COMPONENTS

B. C. Cadoff, Chairman

332-247 O - 69 - 5

PERFORMANCE TESTING—STATE OF THE ART

William R. Herron

Building Research Division
Institute for Applied Technology
National Bureau of Standards

"We are standing at the crossroads." You have heard that expression many, many times. It is applicable today in two senses; first, we are at a crossroad this afternoon in the conference. For a day and a half there has been discussion on performance theory; now the subject changes to performance testing—the process for establishing that a product or system will meet user requirements. In the second sense, the building construction industry is at a similar crossroad, since there have been developed a number of general theories for and approaches to building performance, but there still remains to be developed a complete set of performance standards and tests to validate the concept of performance-based specifications for building construction.

If the performance concept centers on the idea that products, devices, systems or services, can be described and measured in terms of a user's requirements, without regard to the physical characteristics, design, or the method of creation, then the key to development of performance standards and tests is the identification of *significant criteria which characterize the performance expected.* Under the subject of performance testing, the interest is centered on the development of methods for measuring how well the products, processes, or systems meet the significant criteria.

The examples used to illustrate the difference between the performance concept and the materials concept invariably cite a finished product of some sort for the comparison. If buildings in their completed stage had the mass production uniformity of automobiles, electric razors, and household appliances, then the comparisons would be valid. In building construction, however, there is the added complication that each building is a unique assemblage of materials and components chosen (or designed) to produce the desired performance for that particular building. The manufacturer of a product makes design decisions initially and also when he makes a change in model, but the manufacturer of buildings in effect produces a new model each time. The same materials and components may be used in building after building; yet, the total performance produced is unique for each building. The large number of variables involved makes the specifying of performance of buildings difficult. As a result, there has been a tendency to specify materials and products like those that have been used "successfully" in the past, and combine them in a manner which hopefully will result in the desired performance of the completed building. One significant factor to be considered in choosing the material specification is whether the criteria selected will assure the desired performance. Even more important may be the avoidance of unnecessary constraints which might result from the imposition of criteria that are unimportant to the performance expected. Once such constraints are established in specifications and codes, their elimination involves much more than a simple presentation of the attributes of the new in contrast to the old, however logical.

The four speakers to follow this afternoon will discuss in detail the performance testing of some portions of the totality which is called the building. To set the stage for them, I will take a few minutes more to cover the generalities of performance testing, and tell you about some of the work that has been started along these lines here at the National Bureau of Standards.

Under the current system of materials specifying, proof of compliance is accomplished by materials testing rather than by evaluating adequacy of performance. Techniques must be developed for comprehensive testing encompassing complete buildings. The relatively well-developed procedures for testing of materials will reveal whether a materials specification has been met or not. Performance testing however, has not been developed to the point of providing such precise results, because of lack of understanding of the extremely complex interaction between the performances of the con-

stituent materials and components that comprise the complete building.

If user satisfaction is taken as the index of good performance, and that satisfaction is defined as the net subjective response of the user to the collective performance of the elements which constitute the buildings, then performance testing must measure collectively or independently all of the influences that contribute significantly to user satisfaction with a particular whole building, sub-assembly or part. Since the nature of these interactions is not yet fully understood, recourse must be taken to the testing of as complete and as complex a segment of the building as practical. This can be done by full-scale testing of complete building sections, duplicating as necessary the building in use. Since the user cannot judge or articulate meaningfully all of the required performances, hidden and unexpected performance interactions will become clearer through this type of full-scale testing, just as they do in the course of use of buildings over time. Potential problems, such as the failure of reinforced concrete resulting from electrolytic action between it and aluminum conduit encased in it, may not be discovered soon enough if performance testing is not done on the assembly, even though each of the two elements involved met what appeared to be an appropriate material or component specification. An example of the interactions under discussion is the design consideration given to thermal control in buildings by air conditioning. Thermal comfort is not dependent upon temperatures alone—it is also influenced by air velocity and humidity. Too high an air velocity can rob the body of heat and make the user feel cold. A similar feeling of cold can be induced in an otherwise comfortable enclosure if the relative humidity is greatly reduced. Of course the quality of the thermal environment cannot be made satisfactory if there is an imbalance between the input capacity of the air conditioning equipment and the requirements dictated by the size of the enclosure and the thermal insulation. We can, however, make trade-offs over a wide range between the various factors which combine to produce a satisfactory environment, and achieve it in an almost infinite number of combinations. If other design considerations cause constraint on any of these factors, the imbalance can sometimes be overcome by making a trade-off between this constraint and the remaining factors to produce thermal comfort.

For further illustration, I will split performance into two parts and call them quality and quantity. Quality here is defined as the ingredient of performance which is inherent in the properties of the material, whereas quantity is the ingredient of size or amount introduced by the designer of the building. As an example, the air door used in some commercial buildings illustrates innovative possibilities inherent in the performance concept and particularly the division of performance into its quality and quantity elements.

This innovation is not the result of performance testing; there is no effective pertinent test program. The innovative thinking that brought about the air door, however, would almost certainly have been hastened by utilizing the *performance* concept. Previously the concept of access, security and thermal protection has resulted in a solid door as the solution. The air door was made possible by looking at the total performance required. It was not until the benefit of increased access to a commercial establishment was put in its proper perspective with the other performance requirements that the trade-off of increased thermal protection was considered. The access to the establishment was enhanced in both its quality (no door to hinder customers burdened with packages) and its quantity (increased flow of customers). In the process, however, the quality of thermal protection suffered greatly. To restore design balance, it was necessary to increase the quantity element of the thermal protection.

While a comparison of the costs and benefits involved in the use of an air door has proved favorable to its installation under some circumstances, under others, for example residential construction, the need for access is not so paramount that it should take precedence over the cost of increased thermal protection.

Unfortunately, the identification of performance requirements usually begins with an analysis of existing solutions, and will be prejudiced by those solutions until the basic performance requirements can be put into proper perspective. It is only then that the innovative possibilities can be fully exploited. I would like to quote from an editorial in the October 12, 1962 issue of *Science:*

> "The imaginative and original mind need not be overawed by the imposing body of present knowledge or by the complex and costly paraphernalia which today surrounds much of scientific activity. The great shortage in science now is not opportunity, manpower, money, or laboratory space. What is really

needed is more of that healthy skepticism which generates the key idea—The Liberating Concept."

A sure way to produce a favorable environment for the "Liberating Concept" is through the performance concept.

The Building Research Division of the National Bureau of Standards has taken a few steps in the new direction offered by the crossroads marked "Performance Testing." This morning you heard Dr. Pfrang talk about a scalar escalation of structural testing which permits simultaneous testing of floors, ceilings, and walls of two full-scale rooms. In another project, tests were made combining both an increase in specimen size and a comprehensive series of tests on the same types of specimens. These specimens were typical wall sections found in home construction, as prescribed for this series by the sponsor, The Federal Housing Administration. These wall sections, approximately 8 ft x 8 ft (2.44m x 2.44m), were tested for structural, fire, rain and air infiltration, thermal, and mechanical damage characteristics. Although this project was a step in the right direction, more could have been done in testing the same specimen simultaneously for combinations of these characteristics and in more complex combinations of building components. This next incremental increase is what has been proposed in a recent report to The Department of Housing and Urban Development on the subject of a general application of the performance concept to low cost housing.

I will sum it all up by saying it this way—we are looking for performance in building construction. Performance, however, is meaningless taken out of its environmental context. Performance testing restores that context. For example, screen doors have a lot of good performance characteristics, but performance testing would show that they fail to provide some of the more significant attributes expected of a closure for openings in submarine hulls.

PERFORMANCE TESTING OF SANITARY PLUMBING FIXTURES

Paul R. Achenbach

Building Research Division
Institute for Applied Technology
National Bureau of Standards

The Need for Performance Criteria

Much emphasis has been placed on performance requirements and performance criteria during recent years, in seeking to describe the future course of the building industry. Performance is defined only as a noun in the dictionary, and has several different meanings. It may refer to a theatrical program, the mechanical attributes of an automobile such as acceleration, power, speed, etc., or in a more abstract sense, the ability to achieve a desired result. It is in this latter connotation that it is currently being used by leaders in the building industry; as an adjective modifier in terms such as performance requirements, performance criteria, or performance codes. More specifically, the concept of performance of a building material, component, or system is the ability of that building element to fulfill the important requirements of the user, without regard to the materials employed in its construction. The adequacy of performance of the built element would typically be determined in the laboratory by simulated usage tests.

The use of performance criteria is not new. For example, Proverbs 31, believed to have been written about 1000 B.C., lists the performance criteria for a good woman. An incomplete list of these criteria reads as follows:

1. She worketh willingly with her hands,
2. She bringeth her food from afar,
3. She riseth up while it is yet night,
4. She layeth her hands to the spindle,
5. She is not afraid of snow for her household,
6. She openeth her mouth with wisdom.

In a more contemporary frame of reference, the fire endurance requirements for partitions, walls, and floors in building codes have been expressed in performance language for many years. Specifications for air-conditioning units have stipulated cooling capacity requirements under standard test conditions, the ability to operate on over-voltage and under-voltage and at high ambient temperatures, and the ability to dispose of the condensate produced by the cooling coil. On the other hand, a high percentage of the requirements in most building regulations are expressed in specification-type language for which selected materials or classes of materials are identified, arrangement of parts are set forth, or the physical and chemical properties of the raw materials or the elementary materials of construction are required to be within certain limits.

Although the performance concept is not new in relation to the building industry, it has received greater emphasis and has been broadened in scope in the present-day analysis of building design, construction, and evaluation. Everyone is familiar with the use of performance to describe the mechanical attributes of an electric motor, an automobile, or an airplane. However, the use of structural performance to describe how a complete building withstands floor loading, wind forces, and seismic disturbances without excessive deformation, vibration, or cracking; the use of durability performance to describe how it withstands the deteriorating effects of thermal expansion, solar radiation, rain, air contaminants, abrasion, and impact; or the use of environmental performance to assess the thermal, acoustic, illuminating, and spatial properties of an enclosed space are less familiar concepts.

A number of factors in our industrialized society have led to the need for evaluation of the performance of building components and systems. First, a large number of new materials or combinations of materials have been developed for building construction. The specification-type requirements in present-day codes and standards cannot be used to accept or reject these new products, and the question immediately arises as to what performance requirements were essentially satisfied by the more conventional materials which can be used as measures of the adequacy of new materials. For the same reason, the gradual but inevitable replacement of field-assembly of the elements of a building by factory-prefabricated assemblies of considerable complexity and variety has created a strong demand for new evaluation procedures. The promise

of greater economy in building, greater variety in materials and styles, and greater speed of erection with prefabricated assembilies, has accelerated the trend toward factory-assembly of components, even though all of these benefits have not been proven as yet.

The rapid growth in the use of computers in building design has stimulated efforts to evaluate the performance of building systems, because computer methods permit analysis of a larger number of design variables, the study of more complex designs, and a more rapid comparison of alternate designs than was possible by earlier methods of analysis.

Interrelationships in Codes, Standards and Specification Development

In the United States, assurance of strength, safety, sanitation, and health in building construction is usually provided by the requirements written into legal codes. In contrast, the attributes of durability, capacity, efficiency, effectiveness, and aesthetics are provided through specifications. In both cases, the determination of the adequacy of these features in any given building is often determined by reference to appropriate standards, where these are available.

Contemporary codes and specifications employ a high percentage of prescription-type requirements that limit sizes, materials, and designs, and tend to inhibit the introduction of innovation into building practice and to incorporate fewer performance-time requirements. This is regarded as a natural state-of-the-art in building design and construction at the present time for the following reasons:

1. Specification-type requirements are easier to prepare and to administer.
2. It has not been possible to write practical performance requirements for many building components.
3. The test methods to support performance requirements have not been developed in many cases.
4. The necessary laboratory facilities for performance tests are not always available.
5. Agreement has not been reached among interested parties on the performance levels to be required.

Let us look at the steps involved in the development of new test procedures for performance evaluation, and in their incorporation into standards, codes, and specifications. Table 1 lists the principal steps involved in this process.

Table 1. Steps to Performance Requirements for Codes and Specifications

1. Identify performance characteristics[1]
2. Collect statistics on use conditions[1]
3. Determine physical, chemical, engineering properties[1]
4. Develop test procedures for measuring properties
5. Obtain performance data on prototypes or stock models
   (1) Understand technical properties
   (2) Formulate test procedures
   (3) Relate test procedures to functional requirements
   (4) Use as a basis for performance level[1]
6. Standardize test procedures[1]
7. Select performance levels for codes and specifications[1]

The demand for performance requirements for a building component may originate with a manufacturer, a government agency, a standards organization, or a consumer group. It often accompanies the introduction of an innovation into commerce because the existing methods of evaluation are not adequate for the new material or system under consideration. This recognition can lead to the sequence of events illustrated in Table 1.

Example of Performance Criteria Development

The Building Research Division of the National Bureau of Standards has participated in the development of performance requirements for a number of building elements in recent years. Some of the important factors in the process, as well as the difficulties in attaining the ultimate objective, will be illustrated by describing our work on sanitary plumbing fixtures. The request for this study was generated by the appearance on the market of products that could not be adequately evaluated by the existing criteria; viz, bathtubs made of glass-fiber reinforced plastic. The study was sponsored by the Building Research Advisory Board of the National Academy of Sciences-National Academy of Engineering-National Research Coun-

[1] Steps in which cooperative judgment and action are important.

cil, and was carried out under the general direction of a special advisory committee of the sponsor.

At the outset the performance characteristics of a given product are likely to be expressed in qualitative terms related to different facets of the structural, safety, durability, environmental, or aesthetic properties of the products without reference to how they shall be determined or what limits shall be used. This qualitative aspect is illustrated in Table 2, which lists the performance characteristics for sanitary plumbing fixtures that were identified by the special advisory committee of the sponsor. This committee included individuals from industry, academic institutions, government agencies, research organizations, and manufacturers' associations, in order to obtain the broadest spectrum of interests and viewpoints. In fact, experience indicates that a similar consensus of views and judgements is important at several points in the total process of developing performance criteria, as indicated in Table 2, if the results are to receive the desired acceptance in commerce.

Table 2. Performance Characteristics for Sanitary Plumbing Fixtures

A. Structural
- Uniform loading
- Concentrated loading
- Impact loading
- Local deflections
- Drain fitting load
- Watertight joint potential
- Rim load

B. Thermal
- Cracking and crazing
- Maintenance of bond
- Localized heat source

C. Mechanical
- Surface inspection
- Water absorption
- Abrasion
- Impact resistance
- Dimensional stability
- Maintenance of bond
- Cleanability
- Slip resistance
- Scratch resistance
- Drainability

D. Noise Control
- Noise damping
- Sound attenuation

E. Chemical
- Household chemical resistance
- Stain resistance
- Color stability
- Surface texture aging
- Odorlessness

F. Biological
- Micro-organism nutrients
- Vermin resistance
- Dermal toxicity

In order to provide quantitative performance requirements or criteria for a product, tests must be made to measure the properties of the product that most clearly represent these requirements. Thus, having listed the desired performance characteristics in qualitative language, scientific personnel must select those physical, chemical, or engineering properties that can best be used to develop quantitative data on the product. Sometimes this process is straightforward if recognized test methods already exist. For example, the test procedures for steady-state heat transfer of walls are incorporated in one or more ASTM Standards. On the other hand, the properties of a bathtub that best define its cleanability or its ability to withstand dynamic loading are more difficult to appraise, partly because of the lack of prior effort and study of these characteristics. Likewise, in the discipline of durability of materials the relation among impact resistance, hardness, abrasion resistance, and scratch resistance is not clear with respect to a given usage.

In a broad spectrum of performance requirements such as those listed in Table 2, it is easy to pick out a few for which there are generally-accepted test procedures available for reference and use. For other characteristics, such as flame spread, there is a recognized test method for wall and ceiling surfaces, but its scope may or may not logically include sanitary plumbing fixtures. For still other characteristics, such as impact resistance, cleanability, abrasion or wear resistance, and weathering there are several standard test methods each applicable to certain types of materials, products, or uses. Thus, in any of these situations, the paramount question becomes, how well does the proposed or existing test procedure simulate actual use? The exactness of simulation becomes especially critical when products for the same service are manufactured from materials of widely different properties. The difficulty of devising test procedures that are equitable for widely different materials was clearly demonstrated in the study of

sanitary plumbing fixtures made of enameled cast iron, enameled steel, and reinforced polyester resin. A corollary question is, what constitutes actual use? Frequently, a field study of the conditions of use of a given product will yield valuable information and guidance on the following factors:

1. The relative importance of the different performance characteristics,
2. the important physical process pertinent to a given characteristic,
3. the adequacy of simulation represented by a given test procedure,
4. the severity of exposure in use or the range of severity of exposure that is likely to occur, and
5. estimates of the probable useful life expected or attained for the product.

Development of New Test Procedures

The number of performance requirements that are important to the user depends on the state of development of the particular product under consideration and the degree to which the product or system interacts with the user's daily life or represents a status symbol in his community relationships. This can be illustrated by considering the counterpart of the modern bathtub of one or two generations ago in many rural homes, shown in Figure 1. Obviously, the drainability of this fixture was nonexistent for practical purposes. Likewise, such aesthetic properties as stain resistance, scratch resistance, sound attenuation, and color stability were of little importance. Furthermore, this early bathing facility was not accessible or on display on a continuous basis for members of the family and friends as is the modern bathtub.

FIGURE 1. The modern bathtub of one or two generations ago.

In the study of sanitary plumbing fixtures a number of new test procedures were developed and some existing procedures were modified to effect better simulation of the service expected of this type of product. Among the new and modified test procedures were those for dynamic loading, hot-water resistance, resistance to localized heat source, scratch resistance, and drainability.

Figure 2 shows the equipment and apparatus used for dynamic loading of bathtubs to simulate the effect of a fall in the tub or of jumping into a tub. The impact load consisted of a heavy leather bag filled with 150 lb. of lead shot. The bottom of the bag was 9 inches in diameter and was made of a single piece of leather without seams. It was supported from a quick-release mechanism so it could be dropped on a prescribed area of the bottom of the tub from any height. It was found that some tubs were permanently deformed by dropping this load from heights of 18 to 24 inches. However, a limited field survey of similar tubs indicated that permanent deformation of tubs from falls did not appear to be a serious problem in actual use. Nevertheless, such

FIGURE 2. Apparatus used for application of dynamic loading of the interior of a bathtub.

a performance test is recommended to control the installation of tubs of appreciably lower resistance to this type of load.

Figure 3 shows an apparatus developed for studying the scratch resistance of sanitary plumbing fixtures by a hard, sharp object. A field investigation indicated that exposure to scratching was prevalent because children played with toys in bathtubs and because sand was frequently introduced into a tub during bathing. This apparatus consists of a modification of the Porcelain Enamel Institute Gouge Test Apparatus [1] to make it suitable for a scratching test. A reversible motor drives a screw shaft which slides the carriage across the top of the elevating table at a constant velocity. A specimen placed on the carriage is contacted from above by a diamond scratching tool mounted on the underside of a counterweighted lever beam. The load on the scratching tool is calculated from the load on the beam and the lengths of the lever arms. A special viewing box which provides a uniform viewing distance and angle, and a uniform spatial illumination, was used for evaluating the scratches. It was found that the scratch resistance of the various materials used for sanitary plumbing fixtures varied at least 40-fold using this test procedure.

FIGURE 3. Modified PEI Gouge Test apparatus used for investigating the scratch resistance of sanitary plumbing fixtures.

Figure 4 shows an investigator measuring the thickness of material that had to be abraded away to remove the char and discoloration caused by a burning cigarette lying on the rim of a bathtub. The cigarette-burn resistance test provided a rating that was related to the amount of rubbing or abrasion required to remove the char or discoloration caused by a cigarette under prescribed conditions. Cigarette-staining of sanitary plumbing fixtures was found to be moderately prevalent during a limited field investigation.

FIGURE 4. An investigator measures the amount of material that must be scoured away to remove the discoloration and char caused by a cigarette lying on the rim of a bathtub.

Figure 5 illustrates the apparatus and equipment used to evaluate the ability of a bathtub to withstand exposure of the interior surface to hot water without blistering, cracking, checking, or loss of bond between surface coating and base material. A grid of steam pipes equipped with suitable traps, valves, and automatic temperature controls was immersed in a specimen filled with water to the overflow outlet. Tubs were exposed to a variety of

FIGURE 5. Apparatus used for studying the effects of prolonged exposure to hot water on a bathtub.

operating conditions, ranging from 100-hour exposure to water at a temperature of 120 °F. Fiber-glass reinforced polyester resin tubs were found to suffer blistering and fiber-prominence after long exposure to hot water, but further study would be necessary to define precisely the performance requirements.

Collection of Performance Data

After suitable test procedures and apparatuses have been developed, the performance of typical products can be measured under selected test conditions. Here again the desirability of a multi-discipline review of the adequacy of simulation of actual use represented by the test procedures is of the highest importance. Test procedures can sometimes be devised to favor a certain class of materials, and criticism of test procedures is not uncommon when the test results do not reveal desirable properties for all types of specimens.

Prototype or development specimens of a product can sometimes be obtained on which to collect quantitative data. However, more frequently proprietary products are the only specimens available. There are a number of important benefits to be derived from tests of contemporary products in accordance with a comprehensive set of test procedures covering a wide spectrum of properties:

1. Such tests frequently provide a better understanding of the technical properties of a product,
2. the tests often serve to improve the correlation between the test procedures and the qualitative performance requirements,
3. tests of proprietary products usually generate a searching review of the test procedures by the manufacturers and promote greater effort toward fairness on the part of the testing agency, and
4. performance data on available contemporary products usually comprises the only adequate basis for the selection of performance levels.

Examples of test results on contemporary bathtubs related to dynamic loading are shown in Figure 2. Figure 6 shows the range of maximum deflection of several specimens of cast iron, steel, and reinforced polyester resin (FRPE) bathtubs when subjected to the dynamic loading caused by dropping the 150-lb leather bag loaded with lead shot from different heights. The cast iron tubs were

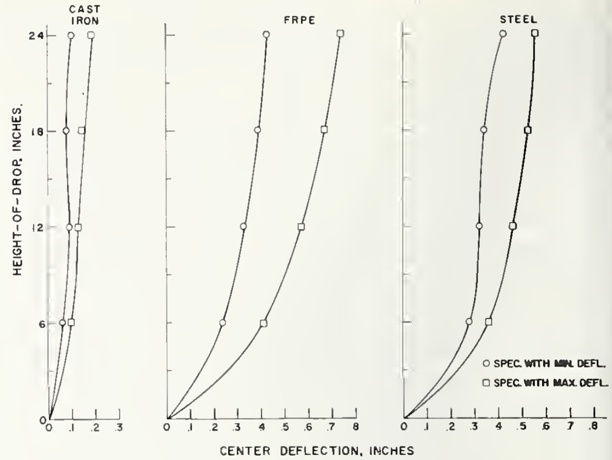


FIGURE 6. Concentrated load test (Dynamic), 150-lb. leather bag.

shown to be the most rigid, and the plastic fixtures the least rigid, of the three types. As mentioned earlier, some of the steel tubs permanently deformed during this test for heights-of-drop in the range of 18 to 24 inches. It was found that the deflections caused by dynamic loading bore no consistent relationship to the deflections of the same specimens caused by static loading at the same point of load application. Thus, there appeared to be no simple way to simulate the effects of dynamic loading by a proportional increase in static loading.

Figure 7 illustrates the effect of slope of the bottom of a bathtub on the time required to drain a specified amount of water and on the amount of water retained as a film or in pools. The principles of orifice flow appear to govern the discharge when the bottom of the tub has any appreciable slope. The drainage of the last one or two hundred milliliters of water appeared to be governed by the principles of film flow, and there is always the possibility of pool-

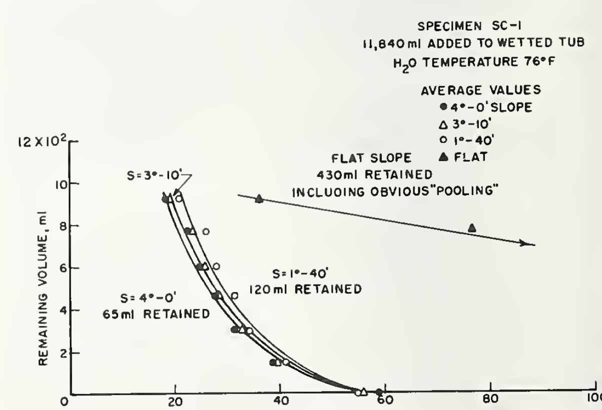


FIGURE 7. Bottom slope effect in bathtub drainage test, regime 2.

ing if the surface is uneven and the average slope is near zero. Table 3 shows drainage data on five bathtubs, some metal and some plastic, in which 98% of the test volume drained out in less than one minute in every case, and the water retained on the bottom surface was less than 100 ml in every case except for specimen PB-3, in which the bottom of the tub had been roughened by a boiling test.

Data of the kind shown in Figures 2 and 3 and in Table 3 are valuable in assessing the realism of simulated test procedures; they provide new technical information on important performance characteristics of these products; and they provide a valuable basis for the selection of performance levels.

Standardization of Test Procedures

Test procedures developed by a manufacturers' association are usually promulgated with the intent of making them standards of that particular industry and for possible wider usage in specifications, contracts, etc. The test procedures typically become standards of the association after review and approval by an engineering committee or a standards committee and after approval by the Boards of Directors. The standardization process by national standards organizations such as ASTM and USASI typically requires one or more reviews by a broader consortium of interests and requires more time for promulgation and approval. Agencies of the Federal Government and the National Academy of Sciences—National Research Council do not promulgate and issue standards, although the Minimum Property Requirements of the Federal Housing Administration are regarded by some people to have many of the characteristics of a standard or code. However, these organizations do in some instances publish reports that contain suggested or recommended test procedures or performance requirements, and frequently bring these recommendations to the attention of national standardizing bodies for consideration in their usual procedures.

TABLE 3. *Results of drainability tests*

Specimen material and identification	Tangent-depth volume [5]	Time to discharge 98% tdv [1]	Volume retained on bottom surface
	ml	*sec*	*ml*
Enameled steel (SC–1)......	3,300	[2] 43.7	[2] 35
		[3] 42.9	[3] 28
		[2] 41.8	[2] 30
		[3] 45.4	[3] 30
Enameled cast iron (CIA–1)...............................	8,600	20.2	18
		19.2	18
		19.7	15
FRPE (PC–4) [4]................	10,710	14.3	44
		15.5	38
		15.4	41
FRPE (PB–3) [4]................	12,000	19.9	109
		19.3	107
		22.0	94
FRPE (PB–2).................	12,000	23.9	67
		25.0	84
		25.1	72

[1] Tangent-depth volume.
[2] Observer A.
[3] Observer B.
[4] Test made after completion of 100-hr boil test.
[5] Tangent-depth volume is defined as the volume of water required to fill the bathtub to a depth such that the water surface coincides with the point of tangency between the inside bottom surface of the bathtub and the curved area at the end opposite the drain, as determined on the longitudinal centerline of the bathtub by means of a straightedge placed on the bottom.

There are a number of benefits that accrue from the standardization of a test procedure, regardless of the type of organization that developed it; namely,

1. standardization represents substantial agreement on measures of value, oftentimes by parties in competition with each other or by even more diverse interests;
2. the process of standardization offers a measure of assurance of objectiveness and comprehensiveness of the test procedure;
3. the promulgation and issuance of a standard attributes the stature of the sponsor to the standard; and
4. the issuance of a standard by a sponsor sets the stage for broad reference and use.

One should not overlook the disadvantage of inflexibility and inertia that is created in commerce if an approved standard is ill-conceived or if the organizational machinery is not maintained for review and revision of the standard as technology changes.

Selection and Implementation of Performance Criteria

The final and most significant step in the development of performance criteria for building products or systems is the selection and implementation of performance levels for use in codes and specifica-

tions. The process for selecting performance levels on a broad basis has not been developed, for the most part. Two procedures have been used, in the main, for this purpose; namely,

1. field or market surveys of greater or lesser scope to develop data on what constitutes typical use conditions, on what characteristics consumers consider important, and on what users consider to be an acceptable useful life of a product;
2. employment of data from simulated usage tests in the laboratory to select performance levels that either upgrade, downgrade, or maintain the existing quality of a class of products in current use.

The first method would be prohibitively expensive and excessively difficult if one proposed to evaluate as many characteristics as were listed earlier in this report for plumbing fixtures. Furthermore, in many areas of performance, such as structural strength, fire safety, durability, etc., most consumers would not be sufficiently well-informed to express useful opinions. Likewise, in some instances there would be no available materials or products that would provide the desired performance levels in all the significant characteristics.

Thus, it appears that the second method described above constitutes the more practical approach to the setting of performance levels. It permits decisions to be made on the basis of quantitative data; it permits tradeoffs between stronger and weaker characteristics of a given class of products; it provides incentives for upgrading of the weaker characteristics of a given product, and it assures that there will be some available products that are responsive to the selected performance levels. This latter process is very imperfectly practiced at the present time, as is indicated by the events that have taken place during the progress of the study of sanitary plumbing fixtures and since completion of the study.

The final report of the study prepared by the National Bureau of Standards was transmitted to the special advisory committee of the Building Research Advisory Board late in 1966 for review and eventual inclusion in their published recommendations. The committee reviewed the recommended test procedures and adopted most of them, while making small revisions to some and a very few substitutions. The report [2] of the committee, issued in February 1968, expressed the opinion that many of the recommended test procedures were complicated and costly to perform, and that the suggested levels of performance had not been correlated with service performance and tended to represent the lowest common denominator among the fixtures tested.

The Federal Housing Administration permitted installation of a limited number of fiber-glass reinforced polyester bathtubs on a trial basis about the time the study was initiated, and issued directives to their field offices permitting the use of these fixtures about the time the actual testing program was completed by the National Bureau of Standards. During the course of the study, revisions of Commercial Standards [2,3] on fiber-glass reinforced polyester bathtubs and shower units prepared by the industry were adopted by the USA Standards Institute under their existing standards procedure.

Conclusions

It is clear from the examples cited that the process for implementing performance requirements for building components is not standardized, but depends on a variety of economic forces and organizational policies. Perhaps the simplest and most expeditious method for utilizing newly developed requirements is to incorporate them into purchase documents. The extensive list of Federal and Military specifications in existence provide an effective mechanism by which test procedures developed by any organization can be put into use in commerce. The modification of model codes and legal codes is a somewhat slower process and, in general, is only applicable to criteria involving strength, safety, and health.

The experience gained at the National Bureau of Standards in the study of sanitary plumbing fixtures described herein, and other similar studies, indicates the following conclusions regarding the development of performance criteria:

1. The process requires several years to complete for any given product.
2. The application of multi-discipline judgement is important at all major steps of the process.
3. Laboratory effort in several disciplines will typically be needed for the development of test procedures.
4. The adequate simulation of use conditions is a key ingredient in developing test procedures applicable to widely different materials.
5. Multi-discipline action at the point of imple-

mentation of performance criteria is a complex part of the process because it involves contractual matters, whose prerogatives are unwillingly shared, in most cases.

References

[1] Test for Resistance of Porcelain Enamels to Gouging, Bulletin T–1, Porcelain Enamel Institute, Inc., Washington, D. C. (1942).

[2] Performance Characteristics for Sanitary Plumbing Fixtures, Building Research Advisory Board, National Academy of Sciences—National Research Council (1968).

[3] Gel-Coated Glass-Fiber Reinforced Polyester Resin Bathtub Units, USA Standard Z121.1 (1967); USA Standards Institute, N.Y., N.Y.

[4] Gel-Coated Glass-Fiber Reinforced Polyester Resin Shower Receptor and Shower Stall Units, USA Standard Z124.2 (1967) ibid.

PERFORMANCE TESTING OF EXTERIOR WALLS: AIR, MOISTURE AND HEAT TRANSFER

Henry E. Robinson

Building Research Division
Institute for Applied Technology
National Bureau of Standards

Abstract*

An apparatus developed for making measurements of air, moisture and heat transfer through exterior walls is described and typical results from tests conducted on four different types of walls is given and discussed.

The apparatus consisted of two boxes with provision for inserting an eight foot by eight foot sample of an exterior wall between them with air and moisture tight seals. The warm box, representing the interior side of the wall, could be controlled over a temperature range of 75 F to 100 F and a relative humidity of 40% to 70%. The apparatus was instrumented to permit measurement of temperature and humidity at different points on the wall, air and water vapor pressure differences between the exterior and interior sides of the wall, heat flow measurements, air volume supplied to either box and deflection of the wall.

The test walls were constructed so that joints typical of the type of wall were included such as vertical joints with panel walls and wall/floor and wall/ceiling joints in all walls.

The behavior of the wall is important and must be considered in the experimental conditions. For example, the amount of water deposited in the wall in the form of ice varied with the type of wall. Under winter conditions the ice impedes the leakage of air and a wall with high leakage under summer conditions may show low leakage under winter conditions after sufficient time for ice formation.

Leakage tests were made with the wall to floor joint sealed and then with the wall to ceiling joint sealed. The effect of this sealing varied widely with the type of wall.

Panel deflection depended upon pressure differences, movement of water and, in some cases, thermal effects.

Humidity sensors are not satisfactory for measuring the accumulation of moisture in the wall because of the difficulty or impossibility of placing them in the correct locations. However, a method was developed that permits the rapid determination of the rate of accumulation of moisture in a wall under any given conditions.

*Abstract prepared by the editors. The speaker did not submit a manuscript.

332-247 O - 69 - 6

PERFORMANCE TESTING OF EXTERIOR WALLS: STRUCTURAL PROPERTIES

Robert G. Mathey and Thomas W. Reichard

Building Research Division
Institute for Applied Technology
National Bureau of Standards

1. Introduction

Earlier during the conference there was considerable discussion of the different terms related to the performance concept of buildings; terms such as performance criteria, performance standards, performance codes, performance requirements, performance limits, and performance characteristics. With regard to the testing of exterior walls and with particular attention to their structural properties, the term performance characteristics is the most significant of those related to the performance concept. The reason for this significance is that in testing exterior walls the primary objective is to measure the behavior characteristics or performance of the walls under anticipated service conditions.

Performance testing of exterior walls to determine their structural properties is carried out for basically two reasons. First, to determine if the walls behave in accordance with prescribed criteria, standards, codes, or other requirements. Secondly, to determine the performance characteristics of acceptable exterior wall systems for the purpose of using this information as a basis for developing performance criteria, standards, and limits that may be applicable to wall systems in general. This second reason provides the subject for this presentation.

What are the desirable performance characteristics of an exterior wall system for residential structures? To what extent are the desired performance characteristics of housing components based on rational design factors? We know that some types of exterior wall systems have gained acceptance through usage over the years, yet their design could be altered somewhat and the wall would still perform satisfactorily.

As an example, critics of conventional construction methods point out that the basis for using wood 2 x 4-in. studs at 16-in. on centers is tradition rather than rational design.

Actually there has been a form of evolutionary development in this type of stud wall. We still say 2 x 4, but today's 2 x 4 is only about 2/3 as large as the original. Through usage, which can be considered full-scale performance testing, it has been determined that the performance of today's stud wall is acceptable.

It is undesirable to wait years to determine if innovations will perform satisfactorily in service. We must be able to evaluate new constructions rapidly and in the laboratory.

In evaluating the structural performance of wall systems a number of factors must be considered, but the most important of these are strength and rigidity.

For some constructions, strength may not be as important as the stiffness, since the maximum resistance to load may not be attained until the wall has been distorted beyond a usable shape. Conversely, a construction utilizing brittle materials may distort very little before failure. It is therefore important that performance requirements for structural components include both deformation and strength limits. This is particularly true in considering the effect of deformation on joints, doors, windows, and wall finishes.

It has been generally assumed that the performance of structural components evaluated by a test method simulating service conditions is comparable to their performance when connected into a structure. This assumption is not necessarily valid for all wall systems, especially if we consider the cellular type of wall construction typical of residential structures. Much of the inherent rigidity and strength of this type of construction is directly attributed to the interaction between the various components. When the methods of connecting the components are faulty or inadequate, the strength and rigidity of the structure is questionable even if the component performance is more than adequate.

Performance testing of exterior wall systems with respect to their structural properties will be illustrated by using as examples two investigations carried out by the Structures Section at the National Bureau of Standards.

In view of present accepted practice in this country in this technological area, common U.S. units of measurement have been used throughout this paper. In recognition of the position of the USA as a signatory to the General Conference on Weights and Measures, which gave official status to the metric SI system of units in 1960, we assist readers interested in making use of the coherent SI units, by giving conversion factors applicable to U.S. units used in this paper.

Length 1 in. = 0.0254* meter
1 ft. = 0.3048* meter

Force 1 lb. (lbf) = 4.448 newton
1 kip = 4448 newton

Stress, Pressure

1 psi = 6895 newton/meter^2
1 psf = 47.88 newton/meter^2

Force per Length

1 kip/in. = 1.751 x 10^5 newton/meter

*Exactly

2. Investigation No. 1—Exterior Walls

The objective of the first investigation was to adapt or develop test methods suitable for the laboratory evaluation of the structural performance of exterior wall constructions such as would be used in one and two family residential structures. In conducting this study, the performance characteristics of a selected group of representative constructions were measured for the purpose of providing guidelines for setting performance levels. In general, load bearing walls were considered, although some were suitable for curtain wall applications.

The characteristics which were selected for study were the rigidity, creep and strength under compressive, transverse and racking forces.

The seven types of wall systems included in this investigation are as follows:

(1) Brick veneer frame wall [brick veneer—1/2 in. Fiberboard—2 x 4 studs, 16 in. o.c.—1/2 in. gypsum board].
(2) Sheathed wood frame with wood siding [wood siding—1/2 in. Fiberboard—2 x 4 studs, 16 in. o.c.—1/2 in. gypsum board].
(3) Furred masonry [4 in. brick—4 in. block—1/2 in. gypsum board].
(4) Aluminum faced sandwich [0.02 in. aluminum skin—3 in. paper honeycomb—0.02 in aluminum skin].
(5) Plywood faced sandwich [1/4 in. plywood—2 1/2 in. foamed polystyrene—1/4 in. plywood].
(6) Prefabricated steel frame with plywood siding [3/8 in. plywood—18 ga. galv. "Z" studs at vertical edges and center—2 in. fiberglass—1/2 in. gypsum board].
(7) Unsheathed wood frame with a 1 x 4 let-in diagonal brace and aluminum siding [0.019 in. aluminum siding—1/2 in. foamed polystyrene—2 x 4 studs, 16 in. o.c.—1/2 in. gypsum board].

It can be seen that these seven types of wall systems cover a wide range of constructions.

These seven exterior wall systems were subjected to the following three types of structural tests:

(1) Compressive test
(2) Transverse load test
(3) Racking load test

Compressive Test

The purpose of the compressive test was to determine the performance of the test wall panels under an axial compressive load. Compressive loads in service are produced by the weight of the roof, second story walls and floors, building contents and occupants, and snow and wind loads on the roof.

The test specimens were 4 ft wide, 8 ft high, and were tested as recommended in ASTM E-72, Standard Methods of Conducting Strength Tests of Panels for Building Construction. The sheathed and unsheathed wood frame wall panels were constructed by laboratory personnel. The prefabricated wall panels were obtained commercially and were tested as received after attaching 2 x 4 plates to the top and bottom in order to provide for application and distribution of load. Single specimens of each of the seven types of wall constructions were tested although it would have been preferable to test at least three specimens of each type. The load was applied over a line one-third the structural thickness from the inside face of the structural portion of the wall.[1] The measurements conducted during the tests were the shortening of the walls, the shortening set, the mid-height deflection and the deflection set.

[1] The structural thickness was taken as the width of the studs in the wood, steel-framed, and brick veneer walls; the actual thickness of the sandwich walls; and the thickness of the masonry in the furred masonry walls.

Transverse Load Test

The purpose of the transverse load test was to evaluate the strength and rigidity of the wall panels in resisting a distributed load on the exterior surface. This type of loading is caused by the wind acting on the exterior face of the wall. The reverse of this loading which was not carried out in these tests is caused by the negative pressure on the leeward side of the structure.

Two types of transverse load test were carried out on single specimens for each type of test. In the first, the 4 x 8 ft wall panels were tested simply supported in flexure with bending taking place along the length normally considered the height of the wall. Two symmetrically placed loads were applied to the exterior face of the wall panels at the quarter points over a 90-in. span. Deflections at midspan were measured and in general the tests were carried out in accordance with the requirements of ASTM Standard E-72.

The second type of transverse test was one developed at NBS. In this test the 8 x 8 ft wall specimens were tested in a chamber under a uniformly distributed load with the edges restrained. The chamber was basically a large box with an open front against which the specimen was placed with the exterior of the wall facing inward. The open front was framed with steel channels to provide a stiff frame for the specimen. Loads were applied to the exterior face of the wall by pressurizing the interior of the chamber. The load was determined by measuring the chamber pressure with a precision manometer. Loads of up to 50 psf could be applied to the wall panels. A 50 psf load corresponds to the force resulting from a wind of approximately 110 mph. Deflection and deflection set of the wall specimens were measured at 13 different locations. Data from this second type of transverse test are not presented. However, these data were considered in determining the recommended performance limits reported in the paper.

Racking Load Test

The third and final test was the racking load test. The purpose of this test was to evaluate the resistance of a wall to a lateral end thrust applied near the top of the wall. This end thrust in service is usually considered to be that caused by the action of wind on a connecting wall at right angles to the wall in question. A similar end thrust might also be caused by earthquake forces.

The test specimen consisted of a nominal 8 x 8 ft portion of the wall complete with exterior and interior finish materials. All parts normally required when fastening the wall to a structure were included. When applicable, the recommendations of ASTM E-72 (Standard Methods of Conducting Strength Tests of Panels for Building Construction) were followed in the fabrication of the test specimens.

A proposed NBS diagonal compression test method illustrated in Figure 1 was used for the racking test in lieu of the ASTM E-72 method. The apparatus consisted of a loading yoke, a displacement measuring gage, and a lateral support system to prevent lateral movement of the specimen during test. Basically, the loading yoke was a hydraulic jacking device suitable for applying a compressive load between the diagonal corners of the wall, and included a load measurement device. The displacement measuring system was used to measure the change in length of the diagonal. The lateral support was provided by a system of steel brackets and heavy-duty casters. All walls were tested horizontally for convenience. The brick veneer and masonry walls were not tested in this investigation. Data from previous studies were utilized [1], [2], [3].

Additional apparatus was designed so that the performance of the exterior wall systems could be evaluated under combined compressive and racking loads. The compressive loading apparatus consisted of a series of springs and tie-bar yokes shown in Figure 2 that were suitable for applying and sustaining compressive loads up to 2000 lb at each of five uniformly spaced positions on the walls. The spring-yoke assembly was made so that it did not physically interfere with the diagonal racking load equipment.

After applying the predetermined compressive load, the testing procedure was to build up the racking load to the required increment, hold the load for 10 seconds, make the displacement measurement, then release the load. Ten seconds after load release, the displacement reading corresponding to zero load was taken. These 10-second waiting periods were considered to be more important than the loading rate in determining the permanent set which is caused by time-dependent creep.

The determination of the failure load for some wall systems was not obvious. For most cases the usual criterion is the point at which the load falls off while continuing to strain the specimen at a constant rate. For the sheathed wood wall frame, the

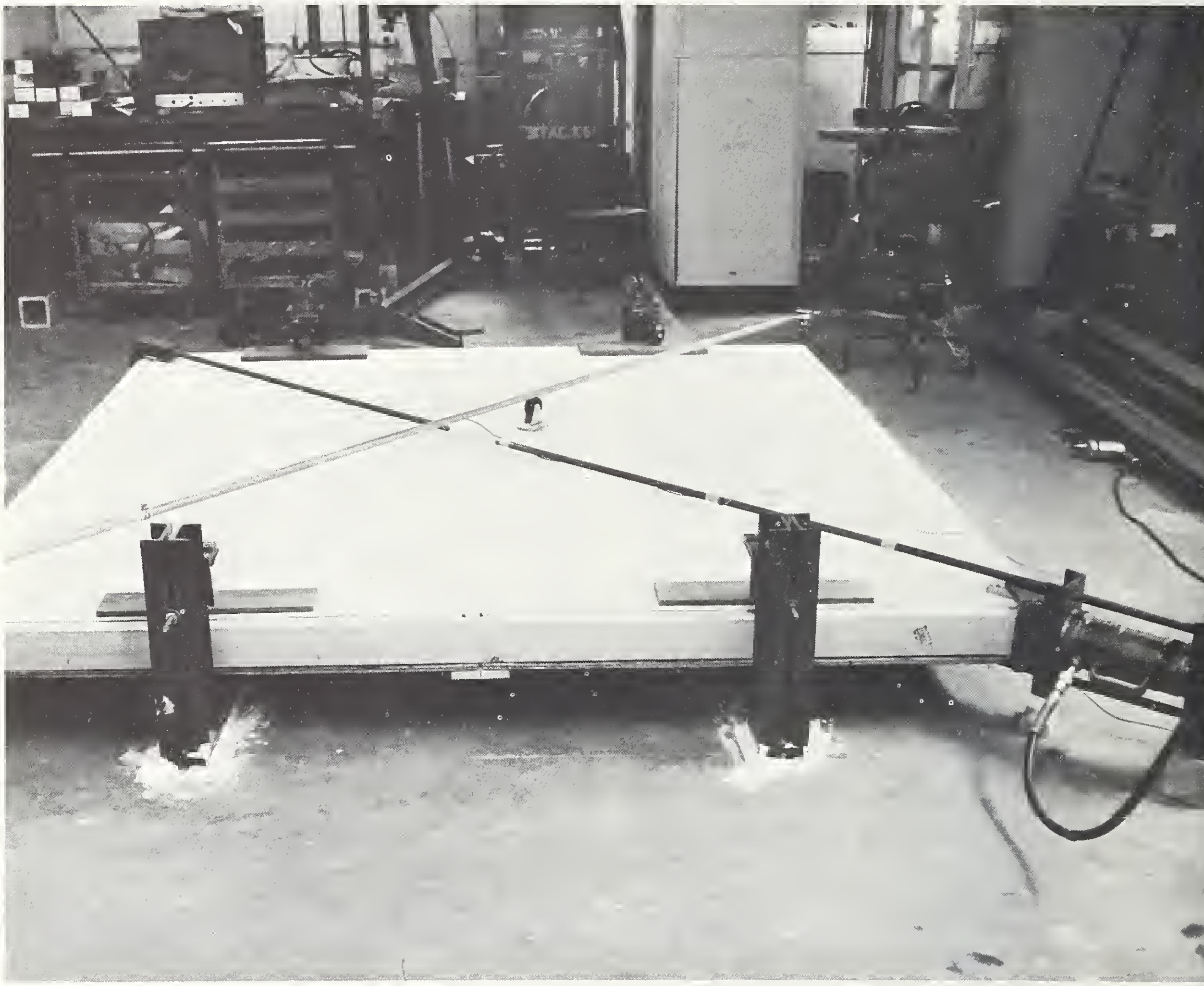


FIGURE 1. NBS Diagonal Racking Test Method.

plywood-faced sandwich, and the steel framed walls, the rate of strain near the failure point greatly influenced the maximum load. An attempt was made to prevent an increase of the straining rate as the specimen started to yield.

Results

As expected from tests of these walls having considerably different properties, the results covered a wide range of values. From a brief look at only a portion of the data some comparisons can be made of the performance of the wall systems.

In the compressive test, the maximum compressive load applied to a 4 ft width of wall ranged from 12.4 kip for the steel frame to 212 kip for the furred masonry wall. Maximum compressive loads sustained by the other 5 types of wall panels along with the type of failure are given in Table 1.

In the transverse test, Table 2, the maximum load applied to a 4-ft width of wall ranged from 41 psf for the furred masonry to 329 psf for the sheathed wood frame. The midspan deflection at 25 psf ranged from 0.01 in. for the furred masonry to 0.31 in. for the unsheathed wood frame. Values for midspan deflection corresponding to a load of 50 psf are also given in Table 2.

From the racking test data presented in Table 3, it can be seen that the maximum horizontal racking load on 8 x 8-ft wall panels varied from 3.5 kip for the aluminum faced sandwich wall panel to over 50 kips for the brick veneer wall. It was difficult to evaluate the racking strength of the aluminum faced sandwich wall because failure occurred in the connections; the sheet-metal screws were torn out of the aluminum skins at very low racking loads. However, when this type of wall is used in a structure it

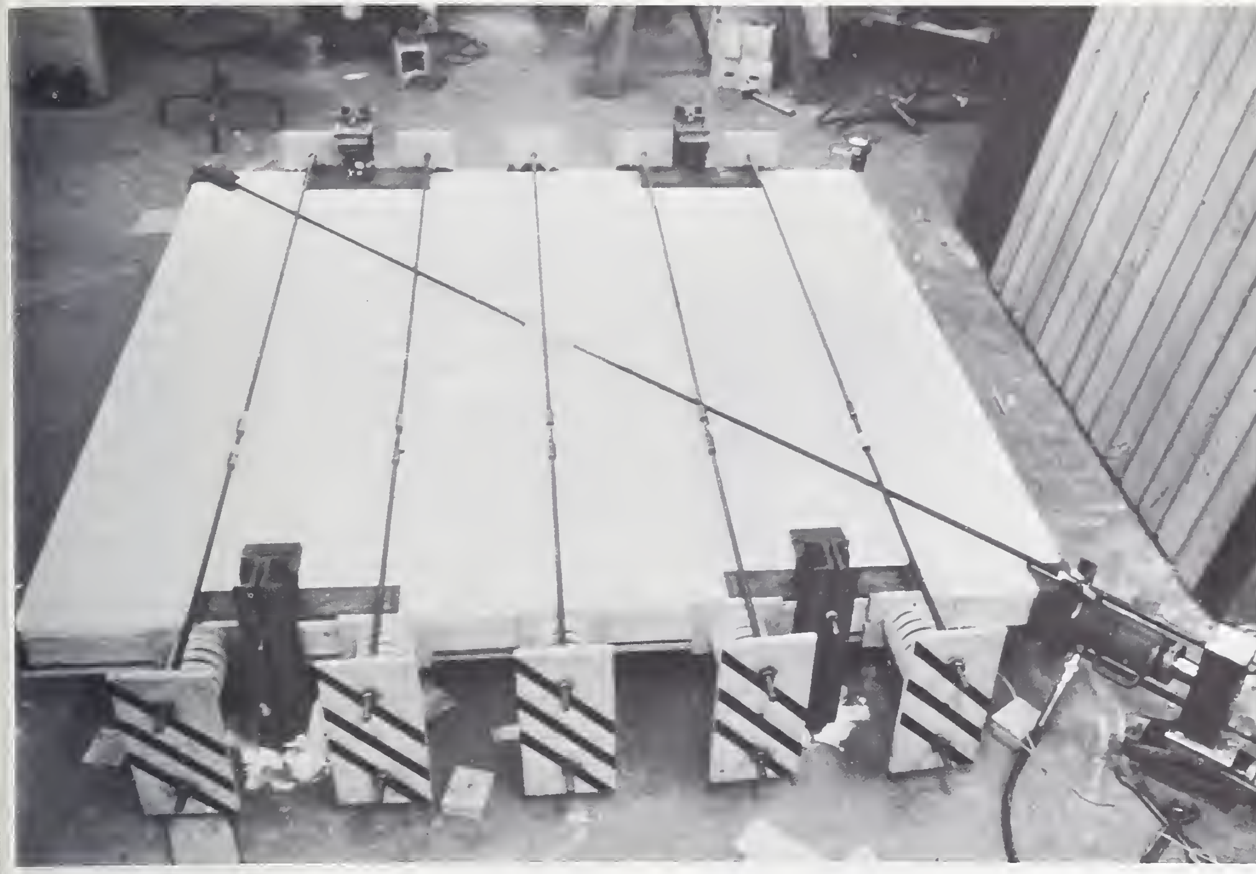


FIGURE 2. NBS Combined Compressive and Racking Test Method.

TABLE 1. *Compressive Test Data (Strength and Type of Failure)*

Wall type	Maximum load for a 4-ft width of wall	Type of failure
	Kip	
Brick veneer........	22.2	Rotation of top plate about inside face of studs.
Sheathed wood frame.	41.8	Fracture across grain of both end studs at knots. One end stud split.
Furred masonry ...	212.0	Face shells of 4-in. back up units crushed in top course.
Aluminum faced sandwich.	12.5	Inside aluminum skin buckled near top.
Plywood faced sandwich.	72.1	Inside plywood skin buckled near top.
Steel frame..........	12.4	Steel Z-studs buckled near bottom plate.
Unsheathed wood frame.	23.6	Excessive buckling of wall. No permanent damage except stud indent in top plate.

appears to perform adequately because of the rigidity offered by the framing at the top and bottom of the wall.

It will be recalled that the primary objective of this study was to determine the methods of test that are necessary to evaluate the performance of exterior wall systems for one and two family residences. With regard to structural properties, the compressive, transverse, and racking strengths and related deformations and deflections were selected as the most important performance characteristics.

ASTM E-72 test methods with modifications in some cases, along with NBS proposed test methods, were found to be satisfactory in evaluating performance of the exterior wall systems.

Recommendations

Based on the limited data resulting from this study and data from other investigations [3], [4], [5] that substantiate in part the test results, the following performance limits were recommended.

TABLE 2. *Transverse Test Data, Quarter-Point Loading of 4-ft Wide Wall Panels* [1]

Wall type	Midspan deflection at		Permanent [2] set for 50 psf	Maximum load	Method of failure
	25 psf	50 psf			
	in.	*in.*	*in.*	*psf*	
Brick veneer	....	....	....	319	Fracture of studs.
Sheathed wood frame	0.10	0.20	....	329	Do.
Furred masonry	.01	....	....	41	Bond failure of header courses in block.
Aluminum faced sandwich	.21	.43	0.05	139	Sudden shear failure of panel near one support.
Plywood faced sandwich	.19	.36	.03	287	Sudden fracture of edge piece near load point and fracture of tension-face plywood.
Steel frame	.14	.24	.06	163	Steel studs slowly buckled at load points.
Unsheathed wood frame	.31	.56	.17	211	Sudden fracture of one edge stud.

[1] Concentrated loads were converted to equivalent uniform loads. [2] From curve extrapolated to zero load.

TABLE 3. *Racking Test Data (Rigidity and Strength) for 8 × 8-ft Wall Panels* [1]

Wall type	Rigidity [2]		Maximum load	Type of failure	
	At load of 3000-lb [4]	At displacement of 0.2 in [5]		At initial indication of failure	Final failure
	Kip/in.	*Kip/in.*	*Kip*		
Brick veneer	....	240.0	50. +	Plaster cracked at displacement of 0.46-in.	Did not fail at reported maximum load.
Sheathed wood frame	130.0	31.8	9.7	Cracking of taped joint of plaster board at average horizontal load of 6.3 kip and displacement of 0.23 in.	Diagonal crack in fiberboard sheathing across corners.
Furred [3] masonry	1800.0	....	46.4	Diagonal crack between load points in mortar around masonry units.	Same as initial.
Aluminum faced sandwich.	246.0	....	3.5	Buckling of aluminum connecting angles at panel, joint, top and bottom.	Crushing of corners at load point.
Plywood faced sandwich	30.0	18.4	11.0	Differential movement between panels.	Crushing of wood at shear-pin holes.
Steel frame	15.6	15.2	4.8	Differential movement between panels, joint cracked.	Splitting of 2 × 4 in. top and bottom plates, and enlargement of shear-pin holes in studs.
Unsheathed wood frame	24.4	21.8	7.0	Buckling of aluminum siding over let-in brace.	Fracture of let-in brace. No distress in plaster board or taped joint.

[1] Loads and displacements are the horizontal equivalents of the measured diagonal values.

[2] Rigidity is the measured load divided by the displacement at that load.

[3] No interior finish.

[4] 3000-lb. is a typical design racking load.

[5] FHA Technical Circular No. 12 requires a minimum rigidity of 6 kip/in. at a displacement of 0.2 in. for a sheathed 2 × 4 stud wall without interior and exterior finish materials.

(1) The allowable compressive load should not exceed 50% of the least-strength [2] for flexible construction and 40% for construction of unreinforced brittle materials.

(2) The allowable racking and transverse loads should not exceed 60% of the least-strength for flexible constructions and 50% for constructions of unreinforced brittle materials.

[2] Least-strength is the minimum value determined in tests of at least three specimens.

(3) The lateral deflection at mid-height of the wall under the design transverse or compressive load should not exceed 10% of the structural thickness of the wall.

(4) The shortening of an 8-ft. high wall under the design compressive load should not exceed 0.25 in.

(5) The horizontal displacement along the top of an 8-ft. high wall when under the design racking load should not exceed 0.20 in.

(6) The permanent set resulting from any type of loading should not exceed 50% of the allowable maximum deflection or displacement.

The values given in the recommended performance limits were based on a factor of safety for strength properties, and on limiting values of deflection and deformation with regard to the opening and closing of windows and doors, cracking of interior wall finishes, and water penetration of exterior walls. Based on typical design loads, the walls tested in this study met the requirements of the recommended performance limits, with the following two exceptions.

> The allowable transverse load on the furred masonry wall was only 20.5 psf and excessive deflection of the unsheathed wood-framed wall would be expected for wind loads exceeding 25 psf.

3. Investigation No. 2 – Masonry Walls

The second example of performance testing of walls is an investigation recently carried out at NBS regarding strength and rigidity of masonry. In selecting the performance characteristics to be studied, the behavior of masonry walls in vertical and horizontal flexure under lateral loading, compression, and racking were considered most important. In addition, the effect of compressive vertical loads on these characteristics was considered to be worthy of study.

Combined Compressive and Transverse Load Tests

In one phase of the investigation, the compressive and transverse load test methods of ASTM Standard E-72 were combined in order to investigate the effect of compressive vertical loads on the flexural strength of the wall panels. In these tests a predetermined compressive vertical load was applied to the wall panel with a hydraulic testing machine and then a uniformly applied transverse load was applied using a reaction frame and an air bag.

Approximately eight specimens of each of eight wall constructions were tested in the test setup illustrated in Figure 3. From these tests information

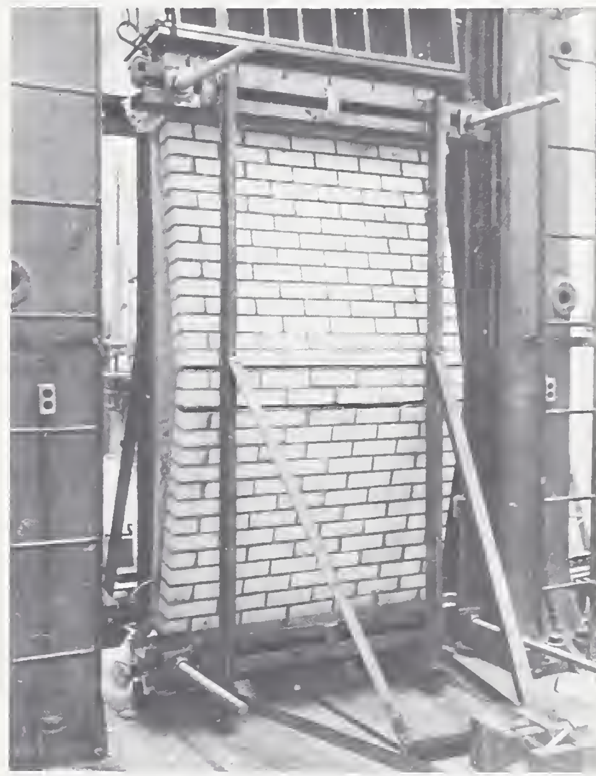


FIGURE 3. Combined compressive and uniform transverse load test on a 4 x 8 ft masonry wall. The uniform transverse load was applied by means of an air bag attached to the steel reaction frame on the opposite face of the wall.

was provided which allowed construction of interaction diagrams that represent the combinations of axial thrust and moment which result in failure of the walls. A typical interaction diagram for a brick wall panel 4-ft wide and 8-ft high is shown in Figure 4. It can be seen from this figure that the wall panel resisted considerably greater uniform transverse load when a compressive vertical load was applied to the wall. Maximum flexural stress was developed from a transverse load when the compressive load was approximately 40 percent of the compressive strength of the wall.

In another phase of this study the effects of the

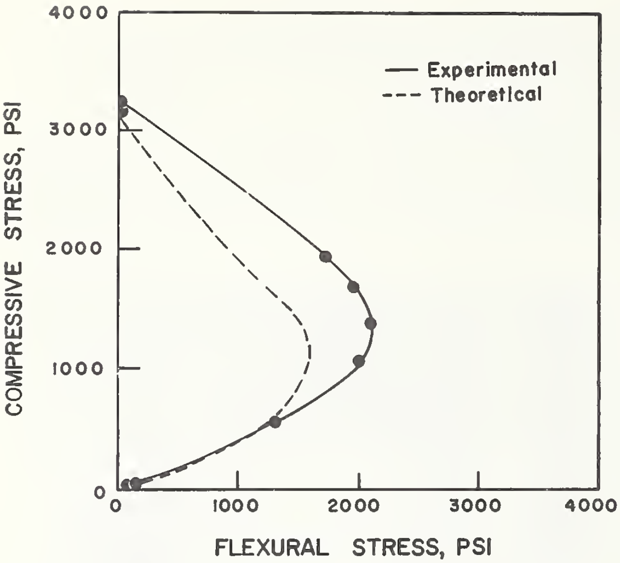


FIGURE 4. Typical interaction diagram for 4 x 8 ft brick wall panels representing the combinations of compressive stress and flexural stress that resulted in failure.

height-to-thickness ratio and eccentricity of load were investigated by testing masonry walls that ranged from 10 to 20 ft in height.

Racking Load Tests

In carrying out racking tests of masonry the objectives were to develop methods of test to evaluate the performance of masonry under racking forces, to provide data in order to develop a rational explanation of the behavior of walls subjected to racking forces, and to provide data necessary for recommending stresses needed for design purposes. For this phase of the investigation wall specimens were tested in a number of different ways; loaded across the diagonal with and without superimposed vertical load, loaded horizontally along the top of the wall while subject to vertical loads, and tested in a manner similar to that described in ASTM E-72. Instead of vertical tie down bars, a hydraulic ram was used as a reaction on top of the wall to prevent overturning. The movements and deformations were measured electronically and were automatically recorded. The effect of specimen size, the effect of the aspect ratio of the specimen, the effect of the magnitude of the superimposed vertical loads on the compressive and racking strength were considered in determining the performance characteristics of the wall panels.

4. Conclusions

In summary, the performance testing of walls requires the measurement of the behavior of the walls under simulated service conditions. The important performance characteristics must be identified and measured. Methods of testing to provide simulated service conditions need to be used or developed if they do not exist. Instrumentation is needed to record the movements, deformations, deflections, and any other measurements that are necessary. Finally, there should be reasonable assurance that the behavior of the exterior wall systems tested in the laboratory agrees with the behavior of the walls in the structure. To obtain this assurance is not an easy task, and it is recommended that more effort should be directed toward correlating the performance characteristics determined in the laboratory with those determined in the field.

References

[1] Fishburn, Cyrus C., Effect of Mortar Properties on Strength of Masonry, NBS Monograph No. 36, November 1961.

[2] Whittemore H. L. and Stang, A. H., Structural Properties of Insulite and Insulite Partition Constructions, NBS Report, BMS 31, October 1939.

[3] Whittemore, H. L., et al, Strength of Houses, NBS Report BMS 109, April 1948.

[4] Clouser, William S., Creep of Small Wood Beams Under Constant Bending Load, Forest Products Laboratory Report No. 2150, September 1959.

[5] Anderson, L. O., Guides to Improved Framed Walls for Houses, U.S. Forest Service Research Paper FPL31, August 1965.

PERFORMANCE TESTING OF FLOOR COVERINGS

Winthrop C. Wolfe and William C. Cullen

Building Research Division
Institute for Applied Technology
National Bureau of Standards

Introduction

Floors and floor coverings are more or less taken for granted, but many properties are involved in the selection and use of these products. For example, manufacturing concerns are interested in durable floors for their factories. Office buildings require floors which are economical and resistant to wear from walking traffic. Hospitals need floor coverings which are sanitary and which will allow for free movement of beds, stretchers, food carts, portable X-ray units, and other mobile equipment. Owners of restaurants, hotels, motels, and private homes want attractive, easy to clean and durable floors.

A good deal of the marketing of floor coverings is based on the interplay between the advertising and sales promotion of sellers and the desires and judgment of buyers. Some consumers, however, purchase on the basis of material specifications and test products which sellers offer to them. Among the pertinent tests are those which show the quality of the materials or construction of the product. For example, a buyer might analyze vinyl asbestos tile for vinyl content or examine carpet for density and pile height. Performance tests, on the other hand, are tests of product behavior properties considered to be desirable by consumers, and are designed to show how products will perform in use over a reasonable period of time. For example, an abrasion test might be performed to show how long a floor covering might be expected to last; a fire test might be run for safety reasons.

Some performance requirements are subjective and are difficult or impossible to evaluate by laboratory test. Color, gloss, pattern, texture, and sensory "feel" are important in sales and consumer acceptance but do not lend themselves to rigorous scientific analysis in this connection. Color, color changes, and gloss can be measured but their relationship to performance requirements is highly subjective. The consumer must decide which color is preferred or whether a glossy or matte finish is the more acceptable. Other performance requirements, however, are objective and are of great practical importance. Some performance requirements refer to the state of the product as delivered. For example, the product as furnished to the consumer should be sanitary, flame resistant, non-slip, resistant to static charge, allow easy movement of wheeled equipment, be comfortable to walk on, quiet, easy to maintain, and spot resistant. Other requirements refer to retention of desirable properties in use, or the time dimension of properties, and might be grouped together as durability or life. Durability, the time dimension of performance, includes resistance to wear, impact, light, water, and other deteriorating factors. Performance tests of durability are difficult as they are attempts to predict future in-service behavior on the basis of short duration tests.

A research program has been initiated by the Materials Durability and Analysis Section of the Building Research Division at the National Bureau of Standards to study the requirements identified above. Under the sponsorship of the Public Health Service, limited laboratory studies of starting and rolling friction and resiliency have already been conducted as part of this program.

Health and Safety—Sanitation

Foremost among the various requirements are properties related to health and safety. This is especially true in the case of hospitals. A floor covering should be sanitary, easy to clean, and should not contribute to the spread of germs, dust, and dirt. This is one concern that hospital management has expressed over the widespread use of carpet in patient areas. While previous studies in private hospitals have indicated that textile type floor coverings are sanitary, further investigations are suggested. Sanitation, or the effect of floor coverings on the biological environment, covers not only the possible spread of disease but allergy from dust, dirt, and particles from the floor covering. This type of work is regarded as

more properly within the purview of the Public Health Service or others expert in this area and is thus not covered in detail in this discussion.

Fire Safety

Another factor which causes some concern about the use of carpet in some areas is fire safety. The question of what kind of carpet is safe from a flammability or flame spread standpoint is important and has not been resolved. No satisfactory test method has been universally accepted. The method frequently used for interior finishes, including carpet, is that described in ASTM Method E–84 and is generally referred to as the tunnel test. The method has been criticized to some extent because the specimens are mounted on the top of the tunnel facing downward. Such a procedure would be expected to produce results differing widely from those obtained in service where floor covering materials always face upward.

Slip Hazard

According to a recent survey [1] falls are one of the greatest causes of accidental deaths. This area is one where research appears to offer possibilities for reducing the incidence and effect of the hazards. Accidents of this type are generally due to slipping or tripping. A slip may be defined as a pedestrian's sudden loss of traction in a forward or backward direction. On the other hand, a trip is a sudden halt in a pedestrian's progress. The person may stumble over an unexpected interposed object or may balk because of a sudden increase of friction in the walkway. Having slipped or tripped, the resilience of the floor covering then becomes a factor in the degree of injury suffered.

Slip hazard is related to the coefficient of friction of the floor covering. A number of devices have been used to measure slipperiness of walkway surfaces. A survey was made of test apparatus and test methods by a task group of the Building Research Advisory Board [2]. The National Bureau of Standards participated in this study. One of the test machines described in the report was the Sigler Slip Tester, which was developed at NBS [3]. This pendulum-impact type of instrument was later modified and is now available commercially as the British Portable Tester. This instrument and its operation are described in ASTM Method E-303, Tentative Method for Measuring Surface Frictional Properties. The design of the British Portable Tester is based on the motion of the foot in walking. Initial test results have indicated, however, that it does not seem well adapted to testing sliperiness of carpet.

Another device which appears to be suitable for on-the-site floor testing is identified as the slipmeter [4]. This device has not been investigated by the National Bureau of Standards.

Static Charge

Many have experienced the static electrical discharge shock people get indoors after walking across a carpeted floor or after sliding across plastic seat covers in a car on cool, dry days. In the winter when homes and vehicles are heated, the environmental humidity becomes quite low. Under these conditions, the body becomes statically charged when people walk across carpeted floors or slide on automobile upholstery. The spark accompanying the discharge on contact with a grounded object, while only annoying at home, may present a hazardous situation in a hospital operating room. Static charge is considered a serious problem in hospital operating rooms and is discomforting and possibly dangerous in other locations within a hospital.

A study of conductive flooring for hospital operating rooms was reported in 1959 by Boone and co-workers [5]. This report describes some of the techniques for evaluating the effectiveness of conductive flooring by measurement of electrical resistance. The problem of evaluating carpet for anti-static property is complicated by the irregular nature of the surface. Considerable work is being done by the carpet industry on anti-static measurement techniques. The methods used are based on the measurement of voltage changes due to walking on carpet or the mechanical application of friction. The maximum voltage generated and the decay or rate of decrease of voltage at the end of the procedure are taken as indicative of the anti-static property of the carpet. A carpet is considered to have good anti-static characteristics if the maximum voltage generated in the test is low and the voltage decay rate is high. Some have suggested that the tribo-electric effect is the basic physical property related to increase in voltage due to walking across carpet, and that the decay rate of voltage is related to the electrical conductance of the carpet. A need is indicated for further studies relating to electrical theory and practical testing.

Convenience—Movement of Wheeled Equipment

Performance characteristics of floor coverings must also be considered in terms of comfort and

convenience. These factors become very important as they affect the essential operations of the building. For example, moving wheeled equipment on the floors is a routine part of hospital operations. Patients' beds are frequently moved and patients are transported to or from the operating suite on wheeled stretchers. Food and linens are brought in on wheeled carts. Sometimes it is necessary to move extremely heavy although mobile X-ray units throughout the hospital. Obviously the floor or floor covering must not impede to any significant extent the movement of these wheeled vehicles.

A laboratory program to study the resistance of floor coverings to the movement of wheeled vehicles has recently been completed at the National Bureau of Standards. This program illustrates the manner in which research to develop test methods can lead to the establishment of performance criteria.

In order to define the problem of pushing wheeled equipment on the floors of a hospital nursing unit, a survey was made of this type of equipment used in the nursing units at the Clinical Center, National Institutes of Health, Bethesda, Maryland. Estimates of the weights of various wheeled vehicles were obtained. In addition, a bed was loaned to NBS for the purpose of the study. The bed was of the manually adjustable type and weighed about 300 pounds, which is considerably lighter than the more modern electrically-adjusted type. Table 1 gives data on types of wheeled equipment common in hospital nursing units.

The manual type of bed was used for the laboratory studies to measure rolling friction. The measurements were made with the bed empty and with a 300 pound load to simulate a patient. Casters for the bed which were used in the study were new, 5 inches (12.7 cm) in diameter, with 1-inch (2.54 cm) wide tread. Two sets of casters (four in each set) were selected for use, one set made of hard rubber

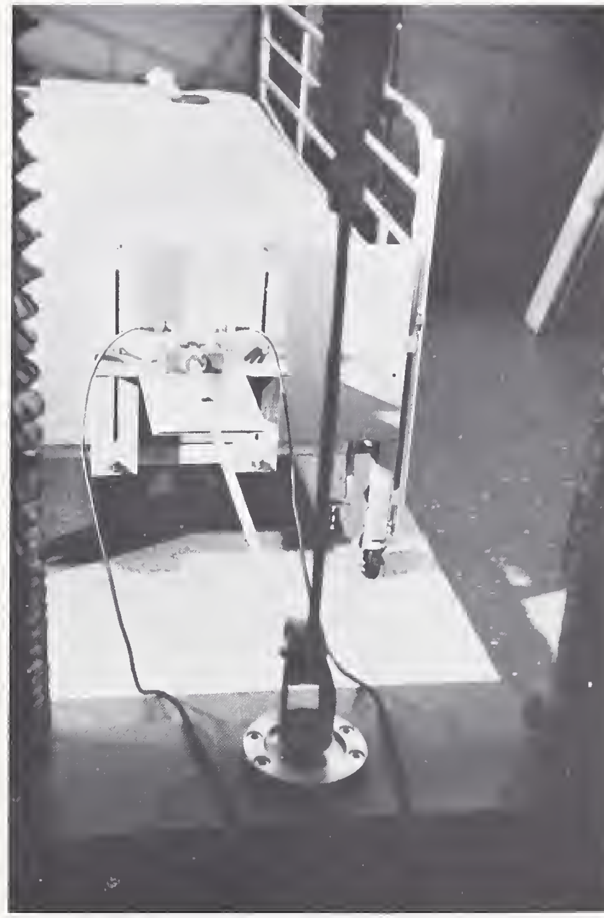


FIGURE 1. Equipment for testing resistance to wheeled equipment. Platform with carpet; hospital bed and connections to load cell, pulley, crosshead of load-strain testing machine.

and the other made of soft rubber. The tests were performed using a load-strain testing machine. A strain gage load cell was connected to the foot of the bed and attached to the crosshead of the testing machine by means of a pulley and cable arrangement. The equipment is illustrated in Figures 1, 2, and 3. Tests were performed at a crosshead speed of 19.7 in. (50 cm) per minute, with the casters or

TABLE 1. *Typical wheeled equipment used in a hospital*

Equipment	Weight	Wheelbase [1]	Track [2]	Casters diameter	Tread width
	pounds [a]	*inches* [b]	*inches* [b]	*inches* [b]	*inches* [b]
Manual bed and patient	500	85	34	5	1
Stretcher and patient	300	42	22	10	1
Mobile X-ray unit	1,000	21			
Front wheels			14	4	1⅛
Rear wheels			22	10	2⅛

[1] The wheelbase is the distance, hub to hub, between front and rear wheels.
[2] The track is the distance between centers of front or rear wheels.

[a] 1 pound = 0.454 kg (approx.).
[b] 1 inch = 2.54 cm (exact).

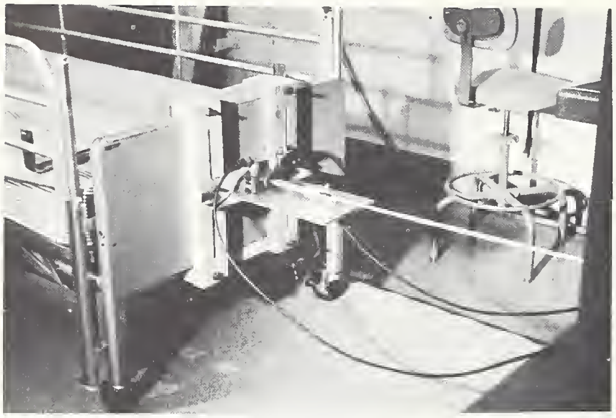


FIGURE 2. Detail of bed, load cell, and connections.

FIGURE 4. Alignment of casters.

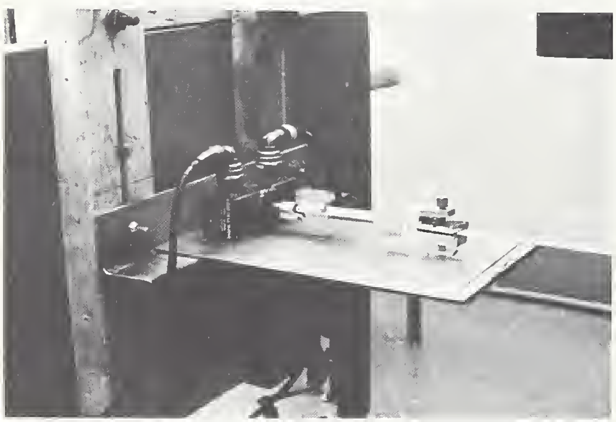


FIGURE 3. Detail of load cell and connections.

wheels carefully aligned in the direction of pull. Alignment of the casters is illustrated in Figure 4. The floor coverings under test were cemented directly to a plywood substrate, with the exception of stretched carpet. The plywood base was then leveled by means of wooden shims. Typical test results are given in Table 2. The measurements were obtained on the loaded bed, weighing 590 pounds (268 kg).

Although the measurements made at NBS required the use of a genuine bed and a platform, 4 by 12 feet (1.22 by 3.66 m) in size, on which the floor covering was applied, it is suggested that a

TABLE 2. *Resistance of floor coverings to a wheeled hospital bed*

Floor covering	Frictional force or load in pounds [a]							
	Hard rubber casters				Soft rubber casters			
	Unloaded [b]		300 lb. load [c]		Unloaded [b]		300 lb. load [c]	
	P_S [d]	P_R [e]	P_S [d]	P_R [e]	P_S [d]	P_R [e]	P_S [d]	P_R [e]
A—Vinyl asbestos tile	11.1	5.3	24.6	13.1	12.0	8.8	28.1	21.2
B—Sheet vinyl	25.9	14.8	34.9	26.5	26.2	15.0	40.4	29.7
C*—Nylon carpet	20.1	15.1	41.3	31.3	18.0	13.4	36.4	28.0
D*—Nylon carpet	17.2	13.3	36.9	27.1	19.6	15.1	38.2	30.9
E*—Nylon carpet	23.8	17.8	47.7	35.8	26.0	20.0	47.4	36.1
F*—Nylon carpet	23.7	17.1	46.4	34.5	19.9	15.1	39.5	31.9
G*—Nylon carpet	33.3	24.9	60.8	46.4	30.4	22.1	52.7	41.0
H*—Olefin carpet	31.6	23.9	57.0	48.5	28.5	21.2	53.5	42.5
I—Indoor-outdoor carpet	24.1	18.2	46.8	36.2	25.5	19.2	46.5	38.0

[a] 1 pound force = 4.45 newtons.
[b] Hospital bed, manually operated, with spring and mattress. Total weight 290 pounds.
[c] Hospital bed, weight 290 pounds, with additional 300 pounds weight.
[d] P_s = Static friction = Force in pounds required to initiate motion. Maximum force recorded.
[e] P_R = Rolling friction = Force in pounds required to sustain motion. Average steady-state force recorded.

C*—Looped pile tufted without backing.
D*—Weave with sponge rubber cushion.
E*—Looped pile tufted, foam rubber cushion.
F*—Looped pile tufted, solid vinyl backing.
G*—Looped pile tufted, sponge vinyl cushion.
H*—With hair felt pad.

somewhat modified test procedure, using a smaller wheeled vehicle, preferably with a kinematic support of three casters, be considered for future test programs. The weight of this smaller test vehicle could be adjusted to simulate the variety of hospital as well as other vehicles used in service and could be designed to accommodate the variety of casters available for wheeled vehicles. Smaller floor assemblies could also be employed. These smaller assemblies would be less expensive, require smaller specimens, and could easily be stored for possible repetitive tests after scheduled soiling, cleaning, or other treatment of the floor covering. Correlation of results obtained with the smaller vehicle with the results of the tests already performed at NBS with the hospital bed would be helpful. The new test could then be proposed as a standard acceptance test, based on performance. Such a standard test would benefit using agencies, as new materials could readily be evaluated to determine their suitability as coverings for floors.

Comfort—Resilience

To most people, soft floor coverings feel more comfortable and luxurious. The subjective impression, at least initially, is that walking on soft floor coverings is less tiring and there appears to be less danger of bodily injury if a fall should occur. This property, however, may be psychological rather than physiological. If there is any physiological advantage in selecting certain floor coverings, it should be related to a measurable physical property. Resilience then becomes an important performance characteristic.

A program was initiated at NBS to develop techniques to measure the energy of compression of floors and floor coverings. If the assumption is made that the subfloor is concrete, which is a valid assumption in the case of most modern hospitals, and since concrete is considered a non-resilient material, the floor covering is the only part of the floor system which contributes to resilience.

In the NBS tests for measuring the energy of compression of floor coverings, the specimens of floor coverings were mounted on cement mortar panels. The assembly was placed on a 10 by 10 by 1 inch (25.4 by 25.4 x 2.54 cm) steel plate. This in turn was placed on a flat cylindrical plate, which was substituted for the lower jaw of the load-strain testing machine. The machine was equipped with a variable speed crosshead and strain gage load cell, connected to a continuous recorder. A flat cylindrical plate was substituted for the upper jaw of the machine. Force was applied to each specimen by means of a cylindrical, flat indentor of 1.125 inch (2.86 cm) diameter, giving one square inch (6.45 cm^2) of contact area. The apparatus and specimen are shown in Figure 5.

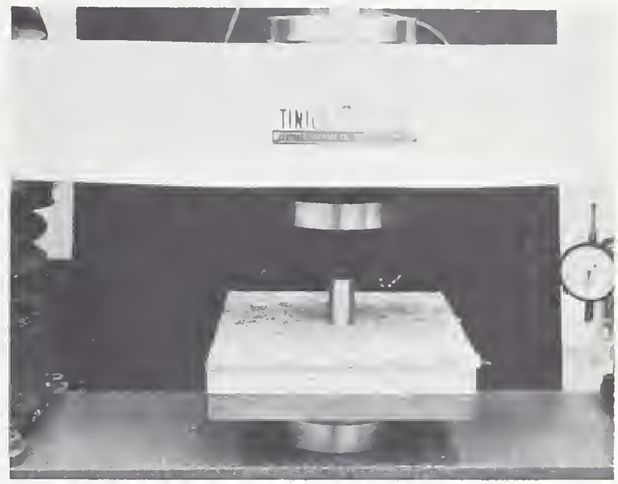


FIGURE 5. Apparatus and specimen for compression-recovery test. Shown from top to bottom: crosshead and load cell; cylindrical plate; cylindrical indentor; carpet sample; cement mortar panel; square steel plate; cylindrical plate.

In performing the test, the steel base plate was first approximately centered with respect to the upper and lower cylindrical plates of the load-strain tester. The composite specimen was then placed on the steel plate and the indentor was placed at the center of the specimen. The crosshead was lowered so that the upper plate just touched the indentor, holding it in place but not exerting any force. The controls were activated and the crosshead lowered at a rate of 0.39 inch min. (1 cm min.) until a load of approximately 220 lbs. (100 kg) was indicated. The direction of crosshead motion was immediately reversed. A curve giving the compression-recovery of the specimen was obtained on the recorder. Typical curves are shown in Figure 6. The energy of compression was taken as the integral of the area under the compression portion of the curve. The maximum force was expressed in pounds and energy of compression in foot-pounds. Since the force, in each case, was exerted over one square inch area, the resulting pressures in pounds per square inch were numerically equal to the force.

The relative values for energy of compression were about what one would expect. Firm materials, such as asphalt and vinyl asbestos tile, showed low energy values, while relatively high energy values

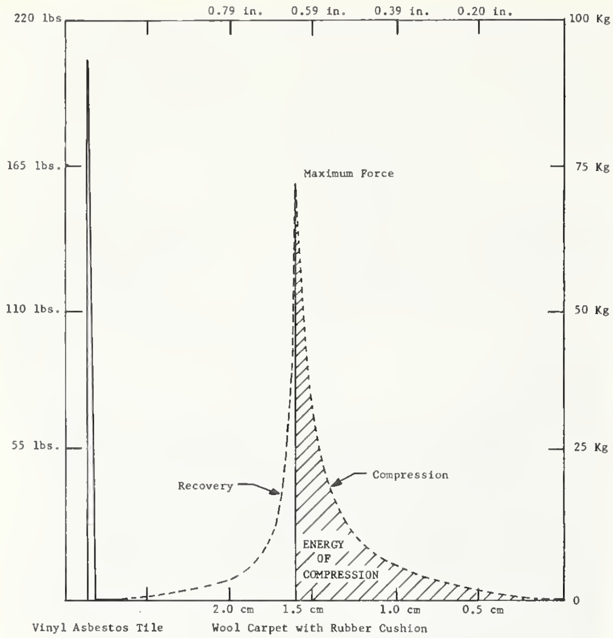


FIGURE 6. Typical compression-recovery curves.

were obtained with soft materials, such as carpets with rubber cushions. These results correlate quite well with subjective experience. A person feels the difference between a hard and soft surface. Carpets feel more "cushiony" and comfortable. Surprisingly, however, the energy values are all quite low, never having been more than two foot-pounds. Results are given in Table 3.

The test results agree with the observations of Holden and Muncey [6], who state that "Variations due to changes in floor surface are almost non-existent, the only noticeable effect being the disappearance of a small impact peak when the subject changes from ordinary floors (concrete, wood) to lawn . . . At first sight it is surprising that the curve for a relatively soft floor like cork tile is almost identical with the curves for wood and concrete. This is probably because in the foot-sock-shoe-floor system the deflection under load occurs almost completely in the flesh area between the skin and bone of the heel and the difference in the deflections of cork and concrete, due to their different Young's moduli, is completely obscured. For the lawn, where the deflection is likely to be comparable with that of the flesh, the impact peak disappears."

Acoustical Properties

Today we live in a noisy world, owing to increase in population and mechanization. Hospitals appear to be no exception and are often noisy places, in spite of the patients' need for rest and quiet. Patients, who are not feeling well, are confined with little to do but listen to the noise. Sounds are transmitted into the patients' rooms from radios, television sets, floor polishing and cleaning machines, carts and clattering dishes, conversations of both

TABLE 3. *Compression energy of floor coverings*

	Maximum force		Energy of compression	
	lbs.	kg.	ft.-lbs.	joules
Asphalt tile (average of three tests)	203	92	0.04	0.05
Vinyl asbestos tile (average of three tests)	195	89	.04	.05
Solid vinyl tile (average of three tests)	182	83	.04	.05
Backed vinyl sheet floor covering	220	100	.13	.18
Cushioned vinyl sheet floor covering				
Brand A (average of three tests)	203	92	.18	.24
Brand B (average of three tests)	197	89	.30	.41
Brand C	220	100	.46	.62
Linoleum, ⅛-inch gauge, burlap backed	291	132	.23	.31
Wool looped pile carpet with hair pad (average of two tests)	188	85	1.15	1.56
Wool looped pile carpet with waffle sponge rubber pad (average of two tests)	176	80	1.06	1.44
Wool looped pile carpet with attached foam rubber cushion	220	100	.79	1.07
Acrylic looped pile carpet with hair pad (average of two tests)	178	81	1.23	1.67
Nylon looped pile tufted carpet	223	101	.42	.57
Nylon looped pile tufted carpet with attached foam rubber cushion	223	101	.47	.64
Nylon modified upholstery weave carpet with attached sponge rubber cushion	202	92	.50	.68
Nylon looped pile tufted carpet with attached sponge vinyl cushion	226	103	.52	.71
Nylon looped pile tufted carpet with solid vinyl backing	227	103	.32	.43
Polypropylene needlepunched non-woven felt carpet	223	101	.58	.79

staff and visitors, machinery inside the hospital, street noises from the outside, and numerous other sources. Surely patients would rest better in a quiet environment.

Specialists in acoustics recognize surface noise and impact sound transmission as contributors to the noise problem. Surface noise is radiated into the environment by contact of people and objects with floors or other hard surfaces. Impact-generated sounds produced by walking on the floor above are often transmitted to the space below.

Acoustical experts recognize the contribution of certain kinds of floor coverings in alleviating the noise problem. Floor coverings which are "soft" or resilient tend to reduce the generation of surface noise and impact sound. Pile floor coverings are "soft" and provide a relatively large area of sound absorbing surface, thus reducing the general overall noise level. Massive floor coverings, of course, help reduce the transmission of airborne sounds.

A reliable method for evaluating the sound absorption of floor coverings is by reverberation chamber measurements [7], but small specimens of floor coverings have been screened for sound absorption by using impedance tube measurements [7]. Standard methods are available to measure impact sound transmission of floor-ceiling assemblies [8]. The relative effects of different floor coverings can be determined by acoustical measurements on the same fundamental system with the different floor coverings in place.

Resistance to Water and Solvents

It is important from the viewpoint of maintenance and sanitation that floor coverings should not soak up water or allow water to penetrate through to the subfloor and become trapped. This situation may provide a breeding ground for microorganisms. Certain materials might remain wet after spillage or wet cleaning. This might result in wet feet, odor, fermentation, mildew stains, and growth of pathogenic organisms.

Solvents, beverages, medications, chemicals, and such common materials as cleaning fluids and nail polish may also damage or be retained by floor coverings. This situation is familiar to experts in "spotting" (removal of concentrated stains) and cleaning.

There are currently no laboratory methods for evaluating floor coverings for moisture and other liquid resistance, suggesting a fertile field for test method development. Such a program would, however, appear to require research more intensive than is justified by present interest in the subject.

Economics

The cost of a flooring system is something which appears difficult to correlate with technology or standardization. It is generally considered to be a matter for the market place. The user states his needs in the form of specifications and frequently awards it to the lowest bidder. Important performance characteristics are, however, related to cost and often strongly influence it. Textile type floor coverings have been considered to be a luxury item because the initial cost is usually higher than that of the conventional asphalt and vinyl asbestos tile commonly used in offices and institutions. Recently some proponents of textile type coverings have argued that these materials are less expensive in the long run because the cost of their maintenance is less than that for those identified as resilient flooring. On this basis, textile type coverings have been promoted for general use in corridors, lobbies, classrooms, general purpose (not executive) offices, and patients' rooms, in office buildings, schools, homes, and hospitals. The argument is that the cost of floor covering should be figured on an annual basis. The whole subject of utility cost of various floor coverings is open to unbiased investigation.

Wear or Durability

One of the most important performance requirements, related to cost and of interest to all consumers, is wear, durability, or life expectancy. How long will it last? A good deal of time, effort, and money has gone into research on test methods to measure wear of floor coverings. There are some excellent studies and review articles on wear of floor coverings and theories for design of test machines to simulate foot traffic [9, 10, 11, 12]. Results of past attempts to correlate laboratory tests with field studies under actual use conditions, however, have been less than satisfactory. The National Bureau of Standards believes that research should be continued at a moderate level on this subject.

Maintenance and Repair

Performance characteristics under this general heading include soilability; cleanability; stain re-

332-247 O - 69 - 7

sistance; ease of stain removal or spotting; and repair or replacement, including patching. There are no laboratory methods for evaluating floor coverings for any of these characteristics. Repairs and replacements are in the province of skilled workmen and may be outside the scope of laboratory tests. It is believed that selective research in these areas might be profitable.

Conclusions and Recommendations

Research at the National Bureau of Standards on resilience and resistance of floor coverings to movement of wheeled equipment provides an example of how performance tests can be developed. Research on test methods in these important areas should be continued. Research on sanitation should be done by an independent laboratory competent in this area. The question of fire safety is already part of a broad program on fire safety and flammability of textiles which has been initiated at the National Bureau of Standards. While the National Bureau of Standards has devoted considerable effort to acoustical properties, slip hazard, and static charge, there is need for more work on floor coverings of all types, including textile and non-textile. Development of test methods in these areas and in others will require supplementary field studies. Little has been done on the development of performance standards for soilability and cleanability, stain removal, and soil transport; these areas require study before embarking on a program. Maintenance cost must be evaluated by means of a field study.

Acknowledgment

This study benefited greatly from the cooperation of the carpet industry and the staffs of the National Bureau of Standards and the National Institutes of Health. The authors wish to specially acknowledge the following persons:

Mr. William H. Rockwell, United States of America Standards Institute, Inc., New York, N.Y. (formerly with American Carpet Institute).

Mr. Howard W. Spence and Mr. Corwin Strong, Clinical Center, National Institutes of Health, Bethesda, Maryland.

Mr. Leopold F. Skoda and Mr. Thomas H. Boone, National Bureau of Standards.

The investigation was sponsored in part by the Division of Hospital and Medical Facilities, Public Health Service, Department of Health, Education and Welfare.

References

[1] Vital Statistics of the United States, **vol. 2**, Part A, Table 122.

[2] Building Research Advisory Board, Federal Construction Council Technical Report No. 43, Causes and Measurement of Walkway Slipperiness, National Academy of Sciences—National Research Council Publication 899, Washington, D.C., 1961.

[3] P. A. Sigler, M. N. Gieb, T. H. Boone, Measurement of the Slipperiness of Walkway Surfaces, J. Res. NBS, **40**, 339 (May 1948), RP 1879.

[4] Charles H. Irvine, A New Slipmeter for Evaluating Walkway Slipperiness, Materials Research and Standards, **7**, No. 12, 535 (Dec. 1967).

[5] Thomas H. Boone, Francis L. Hermach, Edgar H. MacArthur, and Rita C. McAuliff, Conductive Flooring for Hospital Operating Rooms, J. Res. NBS, **63C**, No. 2, 125 (Oct.-Dec. 1959); NBS Monograph 11, March 21, 1960.

[6] T. S. Holden and R. W. Muncey, Pressures on the Human Foot in Walking, Australian Journal of Applied Science, **vol. 4**, No. 3, 405 (1953).

[7] Cyril M. Harris, Acoustical Properties of Carpet, J. of the Acoustical Soc. of America, **vol. 27**, No. 6, 1077 (Nov. 1955).

[8] International Organization for Standardization (ISO) Recommendation R-140 (E), Field and Laboratory Measurement of Airborne and Impact Sound Transmission, 1st ed., Jan. 1960.

[9] F. C. Harper, The Abrasion Resistance of Flooring Materials, Wear, **4**, 461 (1961).

[10] Herbert F. Schiefer and Richard S. Cleveland, Wear of Carpets, J. Res. NBS, **vol. 12**, 155 (Feb. 1934), RP 640.

[11] Herbert F. Schiefer, Wear Testing of Carpets, J. Res. NBS, **vol. 29**, 333 (Nov. 1942), RP 1505.

[12] Martha L. Nensley and Hazel M. Fletcher, A Service Study of Twelve Cotton Broadloom Floor Coverings, Journal of Home Economics, **vol. 47**, No. 2, 110 (Feb. 1955).

SESSION V. BANQUET

L. M. Kushner, Chairman

TECHNOLOGY AND THE CITY: CLOSING THE GAP

Robert C. Weaver, Secretary

Department of Housing and Urban Development

I would suspect that the title of this conference is pretty dull to the average person. "Performance of Buildings—Concept and Measurement" doesn't exactly swing. And it swings even less for the average conference goer, who is far more likely to be concerned about the performance and measurements of Toots Latour at a go-go club downtown than of a GSA office building on Independence Avenue.

But to all of us here, this is an important event.

The reason for that fact is explained in the announcement for this conference.

It says in effect that America has huge problems in furnishing decent shelter for its people. We have made great strides in scientific and technical ability. Where we have fallen short—and this may be oversimplified—is in applying that ability to improving and increasing our supply of shelter.

I say this may be oversimplified. I think we all realize that it is not only the lack of an interdisciplinary approach that makes it difficult to apply technology to shelter problems. There are also constraints imposed by outdated building codes and other matters that are more political than scientific in nature.

Be that as it may, the point here is that we must get on with what this conference came here to do: to exchange ideas and knowledge and to eliminate confusion in the measurement of performance of buildings.

Your announcement also makes the point that we haven't the time to let nature take its slow course in applying our most advanced technology to shelter needs.

We must all agree.

The evidence of population growth and rapid urban expansion is there for all to see. So is evidence that we are not using all our potential in meeting these needs.

The obvious analogy, and the one we see most often and which is indeed valid, is that we have brought together immense resources of money and scientific knowledge to land a man on the moon. But when it comes to man and his shelter, we have not only failed to move into the future, but are not even making use of our existing resources of knowledge, technology, and materials.

But there is another element that is important here.

We have come into a time when public realization of our housing and urban problems is acute, because evidence of these problems is inescapable.

No man today can hide from bad air and the evidence of too much traffic. He can see decay in the city core and the instant blight of too rapid growth at the urban fringe. He cannot escape the facts of poverty and restlessness in the urban ghetto.

Most people realize that given the facts of population growth and increasing urbanization, these problems will be compounded rather than solved unless we give them our full attention and a good deal more of our resources.

Coupled with this wider public realization of urban and housing problems—and obviously corollary to it—is an increased national effort to solve these problems.

In the years since I was first appointed to stewardship of the national housing effort, I have had the privilege of helping shape this national effort. It is remarkable to me, as I look back on those years, how the mood of Congress has changed in that time. Even as late as 1965, a great year for progressive legislation, we had a real donnybrook over the rent supplement program. This good and necessary program was stigmatized as "socialistic" by some of its opponents, and we won passage by a very thin margin.

I can understand why some Congressmen had profound doubts about the program. It appeared to be a radical departure from past Federal programs, in that it directly subsidized rentals for those unable to find decent shelter at a price they could pay. The fact that the Federal Government through FHA had, in effect, been subsidizing shelter for those better off under its mortgage insuring program for many years, was brushed aside.

Winning that battle and going on to make the rent supplement program work was, I believe, an impor-

tant break-through. Congressmen who had voted reluctantly for rent supplements were less reluctant this year when the Administration brought in its new home ownership and rental programs for low-income families, both of which involve a subsidized interest rate. And this was supposed to be a much more conservative Congress than that of 1965.

I am not trying to say we have arrived at nirvana, and that we will not have to maintain our efforts to get these programs funded—a process that is now going on—but I do believe there has been a significant shift in opinion and that despite inevitable setbacks, we will see very little attrition to our good housing and urban programs.

I will talk about the new 1968 legislation at some length in a moment, but first let me make another point, one of great significance to this audience.

As you well know, research on housing and city problems has received little attention from the Federal Government in the past. We did have the beginnings of a national program in the 1950's, but it died rather abruptly.

But today we have in the Department an Office of Urban Technology and Research with sufficient funding to start what we hope will be a continuing and expanding search for solutions to our housing and urban problems. The President has just launched an Urban Institute, in which private and government efforts will be combined to attack these same problems. You have heard from Mr. Craun, of HUD's Low Income Housing Demonstration Program, of another aspect of our experimental program. You heard from Dr. Pfrang, who conducted an unusually important and successful performance test of a low-cost housing system, again for HUD. In our Model Cities Program, we have a massive, nation-wide effort to innovate in housing and urban solutions, and to try them out on a large scale. That, basically, is the largest experimental effort ever launched by any Nation in the area of housing and city problems.

These are signs of the times. These efforts may not be as large as we want, or go as far as we know is necessary, but I am convinced that as a nation we will never again ignore the need for housing and urban research. We cannot afford to do so. That we know.

I think all of you here realize, however, that your efforts here this week are essential and vastly important primarily in connection with the Housing and Urban Development Act of 1968.

This is a very large commitment by the Nation to the people of America's urban places, and it is particularly designed to help those Americans who most need help.

It provides sufficient authorization and Federal aid to expand good traditional programs such as public housing, and urban renewal, and rent supplement housing. It will allow us to implement the Model Cities Program on the level we think essential.

But the major new emphasis is on volume construction of housing. In this category, it is by far the most ambitious and meaningful housing program in the Nation's history—both for Federally-assisted and private building.

And it is here that the things you are doing will have essential and lasting importance.

The President gave us this goal:

The construction of 26.2 million new housing units in the next ten years, in both private and publicly-assisted units. This is a big order when compared with 14.4 million units built in the past ten years.

Public assistance for 4 million new housing units. That is a big order when compared to the half-million of the last decade.

Public assistance to rebuild 2 million existing units.

That is a very large order when compared to the 25,000 units of the last ten years.

In order to meet these goals, we must not only expand effective traditional programs, such as public housing, but we must create a new generation of housing programs.

These are the most important and dramatic:

A new program to give families of low and moderate income the opportunity to buy their own homes. We will subsidize the interest rate on mortgages for these homes, so that the home owner will be paying as little as 1 percent. There will also be a comparable subsidy, again on mortgage interest rate, for rental housing.

We want to expand the rehabilitation of basically sound housing into an effective industry. And we plan to bring local people—those who need work in the affected neighborhoods—into this effort. This is a vitally important part of this program.

We plan to establish National Housing Partnerships between private enterprise and the

Federal Government, with tax incentives to help make the low and moderate income market more attractive to private investors.

The President's goal is to provide assistance during the first three years to begin construction and rehabilitation of 1,470,000 units.

We are engaged here in what I consider one of the most important efforts in the thirty-year history of Federal urban programs. And that is no less than the building and rebuilding in the next ten years of enough good, decent housing to replace substantially all of the substandard housing in America. As long ago as the Housing Act of 1949, Congress declared that the Nation should bring about "the realization as soon as feasible of the goal of a decent home and suitable living environment for every American family . . ."

That was almost 20 years ago. We must make every effort to see that another 20 years does not pass before we fulfill that promise to the American people.

Many of the programs I have mentioned apply for the most part to the cities and urban communities we now have. But to meet fully the needs of a growing population, we have developed still other new programs. One of the most exciting is one that can make possible and practical the planning and building of entirely new communities. Here we can not only dream but carry out the best of which we are capable in urban design.

If these efforts are to succeed, we must have an active and imaginative research program going at all times. We must find new materials, and learn how to use them. We must take the new technology and apply it to building and rebuilding our cities. We must turn researchers loose on our massive problems. We must train more and better urban and housing people, and we must help States and local communities upgrade their own human resources.

We must increase our efficiency in administration, and that we are working very hard to do at the Federal level in our relatively new Department of Housing and Urban Development.

And we must improve the efficiency of our buildings. Decent housing has always been and always will be the first and essential physical component of a decent life. And it will be to our lasting shame if this vastly productive and energetic Nation cannot bring that elemental decency into every American life.

That is your ultimate goal as you confer on such seemingly dry topics as performance testing of exterior walls and of sanitary plumbing fixtures.

I commend you to the excitement of what you are doing.

SESSION VI. TRENDS AND OPPORTUNITIES

J. P. Eberhard, Chairman

PLANNING AND ENGINEERING OF A NEW CITY (COLUMBIA, MARYLAND)

G. D. Wright, Jr.

Bernard Johnson Engineers, Inc.
10221 Wincopin Circle
Columbia, Maryland 21043

Abstract*

The concept of a new town is explained briefly. The town consists of manageable units-the town center, villages, and neighborhoods. The town center contains a hospital, a regional shopping center, restaurant, hotel, theatre, and facilities for other cultural needs. The village center is a focus for much of the active life of the town. It contains stores for weekly shopping, junior and senior high schools and recreation facilities including provision for teenage activities. The neighborhood center, which offers a point of orientation for families and children, includes a playground for preschool children, a nursery and elementary school and a general store. The citizens in a large measure, live, work, sleep, pray and are entertained within the confines of the town.

Planning documents are discussed and their use as the basic economic model for development is illustrated. The planning document contains information about the allocation of space on land use for detached houses, town houses, industrial and public use with a schedule of construction for a ten or fifteen year period.

The planning document is translated into an engineering document. The engineering document shows the associated phases of construction to complement the planning document and the requirements for utilities such as electric, gas, telephone, water and sewer.

The engineering document is translated into computer language. The next step in the development of the engineering planning is to approach the computer program with various questions. A typical question would be given the basic development as determined and set forth by the economic model, what is the financial exposure resulting from underground electric distribution systems. Similar questions can be asked concerning other utilities such as gas, water or sewer.

Information is obtained from the computer about costs per square foot of different types of land use such as residential, commercial or industrial. Total annual electric bills or gas bills can be determined in line with proposed land use. The computer can also give requirements for water use at any period in the development of the project. The answers supplied by the computer assists the planning team in determining the economic advisability of developing any particular area or selecting the next area to be developed. It becomes a probability game.

The applications of the basic planning document, the basic engineering document and the computer program are almost unlimited. A study was made of the feasability of a central heating and chilling plant for the downtown area of Columbia. A comparison was made of the economic advantages of electric heat pumps, electric resistance heating and gas heating.

The financial and social success of a new town are vitally dependent upon an excellent basic planning document, a sound engineering document and a comprehensive computer program that can supply essential information.

---

*Abstract prepared by the editors. The speaker did not submit a manuscript.

THE NATIONAL IN-CITIES EXPERIMENTAL LOW-COST HOUSING RESEARCH AND DEVELOPMENT PROJECT

Philip D. Bush

Vice-President, Kaiser Engineers
Division of Kaiser Industries Corporation
Oakland, California 94604

Kaiser Engineers, under contract with the Department of Housing and Urban Development (HUD), is heading an association of firms that is undertaking Phase II of the National In-Cities Experimental Low-Cost Housing Research and Development Project. This project is a major part of HUD's program to determine how, under what conditions, and to what extent the nation's urban regions can begin to construct rapidly a relatively large amount of lower-cost and, therefore, innovative housing—the characteristics of which are responsive to the fundamental, social, and economic needs of the nation's lower income families.

The Model Cities Program and this experimental project are responsive to the nation's needs for urban redevelopment. In the next 10 years, our nation must build or rehabilitate 26 million units of housing to provide for new family formations, removal of existing housing, and rehabilitation of substandard housing. These requirements represent an annual production level of 2.6 million units per year, or an increase of about one-and-a-half times the recent average annual rate of 1.7 million units per year. Significantly, it has been estimated that 6 to 8 million households will not be able to afford the price necessary to pay for standard housing. Furthermore, the goal of 600,000 housing units per year for low and moderate income families represents a twelve-fold increase over the 50,000 subsidized units currently being produced annually.

The housing industry has, traditionally, been able to construct adequate housing for those with the ability to pay. The national challenge now, however, is to be able to construct lower-cost housing at a rate twelve times greater than ever before accomplished, for costs that are commensurate with the lower-income groups' ability to pay, and designed to meet their needs.

In March of this year, HUD requested proposals from industry to undertake the "In-Cities" project. The In-Cities Project seeks to identify and measure the effects of the major constraints existing within the cities, and which inhibit the introduction of innovation in the production of lower-income housing. Constraints are factors which slow the pace of establishing lower-income housing or inhibit an increase in the pace, increase the cost or inhibit cost reduction, or unfavorably affect acceptability of the housing by the users. The project objectives will be accomplished by carrying out a series of related experiments consisting of actual construction of groups of dwelling units. The experiments will be designed to involve these constraints so as to measure their effects on cost, time and acceptability of the completed housing, and to establish the effectiveness of methods to reduce or eliminate their effects.

From the nineteen proposals submitted, HUD selected three, and early in May awarded contracts for Phase I of the project. One contract was awarded to each of Westinghouse Electric Corporation and a joint venture of Abt Associates, Inc., and Daniel, Mann, Johnson and Mendenhall. The third contract was awarded to Building Systems Development Inc. (BSDI) of San Francisco in association with Kaiser Engineers, General Research Corporation, Real Estate Research Corporation, Turner Construction Company, and OSTI (Organization for Social and Technical Innovation). These three contracts were competitive contract definition efforts with identical comprehensive work programs to be accomplished within a six-week schedule. Each of the three contractors did the following:

1. Studied 25 Model Cities together with some others to provide detailed information needed to assist HUD in ultimate selection of those cities in which housing experiments could be undertaken;
2. Identified, studied, and evaluated new design, construction, and management techniques and systems to be explored in the

conduct of the subsequent housing experiments in specific cities;

3. Worked with city officials, residents, and labor, industrial, and professional groups to determine the critical housing needs and major constraints to housing innovation;
4. Estimated the cost and time of carrying out useful housing experiments; and
5. Suggested to HUD cities and experiments that in interrelated total should be considered for the overall national experiment.

In the course of BSDI/Kaiser's Phase I activities, members of the team visited all of the seven HUD regional offices, and also communicated with the CDA's (City Demonstration Agencies) in each of the cities that HUD assigned to us. Comprehensive questionnaires were sent to each city. The questionnaire dealt in depth with site characteristics, community participation, availability of potential sponsors, availability of seed money, financing, labor, building codes, and other elements of major importance. We also held a briefing conference for representatives of the cities at the Kaiser Center in Oakland to present personally to them the experimental in-cities housing project as visualized by us and to obtain as much information from them as possible.

Data from the questionnaires, along with information contained in the relevant Model Cities' applications and from other sources were organized to provide the basis for evaluating and recommending the cities. The evaluation was based on:

1. Their commitment to provide decent housing for lower income groups;
2. Their desire and willingness to undertake innovative sub-experiments;
3. Their resources to perform the sub-experiments; and
4. Their ability to accommodate one of a comprehensive set of experiments which would have overall long-term meaning.

Over 350 contacts were made with known innovators in the building industry and with manufacturers of building products to obtain the latest current information on technology applicable to the housing process. This survey provided information relative to 81 building systems and 30 sub-systems (electrical, mechanical, structural). The technologies were screened to:

1. determine if they would be available within the time constraints of the program;
2. determine if their performance characteristics were likely to meet the minimum requirements of the probable user; and
3. determine if they showed any potential construction cost reduction or other advantage.

The user-needs requirements of the populations were estimated from a survey of available literature and from the experience of members of our team who have had extensive recent experience in working with the ethnic groups involved. From general studies of social and institutional problems related to lower-income housing, a set of relevant social organization experiments were identified, involving:

1. The use of space;
2. Delivery of social services to the residents;
3. Management of housing developments;
4. Tenant-incentive programs to reduce maintenance costs;
5. "Sweat-equity" programs;
6. Self-help programs; and
7. Involvement of community groups in the planning operation.

At the same time, another group within our team investigated in depth the procedures for obtaining mortgage insurance and financing for innovative housing sub-experiments which appeared possible without legislative action. Sub-experiments involving mortgaging and financing were then developed which appeared suitable for experimentation.

From these evaluations, three distinct sets of sub-experiments emerged, comprising the ingredients for a comprehensive attack on the nationally significant social, financial, and technical problems in producing housing for lower-income families. The sub-experiments were then matched to cities included in the Phase I study. The other two contractor teams, working with their approximately 30 cities each, prepared their Phase I reports in similar fashion.

Subsequently, HUD selected Kaiser Engineers to carry out the actual Phase II experimental program and issued a contract and notice to proceed on June 28, 1968. Kaiser Engineers is compiling a composite of the reports of the three Phase I contractors for publication by HUD. It will be a compendium of their findings with respect to (1) user needs, (2) building technology state-of-the-art, (3) constraints to the establishment of housing for lower-income families, and (4) city information. Currently, we are involved in the design and planning for implementation of the sub-experiments to be carried out in Phase II, including recommen-

dation of the cities in which the sub-experiments should be located. Initial selection of the cities with which appropriate negotiations can commence will be by HUD; the first group of such negotiations are now expected to commence within a very few weeks.

The methodology we used for formulation of the experimental project starts with a statement of a problem which is preventing the construction of low-cost housing for lower-income families and which could be solved by innovative methods, if such innovations were not affected by constraints existing in the "system." One example shown below is the problem of high-density, high-rise dwellings for lower-income families.

Problem Statement:

Many people responsible for public housing believe that high-rise dwelling units are an inappropriate housing type for lower-income families in the inner city. There have been unsatisfactory experiences in the operation of several high-rise projects in various parts of the country. These projects have been expensive to build and costly to operate. They have been subject to vandalism and have high crime rates.

Undesirable features attributed to high-rise projects include:

1. Lack of access to recreation and shopping
2. The corridors and elevators provide opportunity for crime and violence
3. Lack of play areas where mothers can supervise children
4. Lack of adequate social services or facilities (day care centers, meeting rooms)
5. "Project" image — no personal expression for the tenants
6. Inadequate dwelling unit size with resultant overcrowding and lack of privacy.

The competition for land within the inner cities demands a higher density of dwelling units. The economics of the city require that maximum use be made of the land to generate tax income to support the services required. A requirement that housing for lower-income families be built at lower densities may in the long run be more detrimental, since it will discourage the provision of badly needed housing by increasing the land cost of the units, and decreasing the tax income and services which flow to the residents from that income. Lower density will not be possible within existing cities without substantial relocation and consequent disruption.

The current view appears to be that high-rise units should be provided only for elderly lower-income families. This may create further social costs since such projects can result in separation of the elderly from their own families who contribute substantially to their social well-being.

The Housing and Urban Development Act of 1968 places limitation on high-rise structures in low-rent public housing projects for families with children. The forecasted growth of the population in the cities and probable rapid spread of high-density lower-income population areas indicate that the high-rise approach should be re-examined in the "In-Cities" Project to determine the specific factors which affect the costs and acceptability of this form of housing for lower-income families.

Hypothesis:

It is hypothesized that high-rise building can be used to house lower-income families successfully in urban environments with high population density and scarce land. (Success is defined in terms of original and operational cost, construction time, and acceptability to occupants, management and community.)

Previous failures of high-rise dwelling units for lower-income families can be overcome through:

1. Relatively inexpensive design modifications to the internal arrangement and structure of the building and the use of suitable available materials, products and systems.
2. Better planning of the building and its relationship to the surrounding environment.
3. Improved management and maintenance policies and procedures.
4. Improved tenant selection, orientation, and involvement.
5. Integration of communities' activities and social services within the residential structure.

Design hypotheses that would be tested include:

1. Using a basic space allocation for families (according to size) and permitting them a choice of apartment layout and interior finish will result in a greater degree of tenant acceptance.
2. Designing interior space with a high degree of adaptability to a wide range of uses will result in
   (1) a greater acceptability on the part of the tenant since the space can be adjusted as the family changes.
   (2) less cost attendant to the changes in te-

nants and greater response to the needs of different tenants.

3. Using the high-rise building for multiple purposes, including therein the necessary commercial and community facilities for the tenants and the surrounding community (day care center, neighborhood center, snack bar, grocery store, launderette, etc.) will result in greater acceptability of high-rise projects to the tenant and to the surrounding community.
4. Proper "cluster" design of the entry spaces and elevators, and the use of available equipment for security can reduce the incidence of crime and provide greater security in high-rise dwelling units.
5. Improving architectural design to provide pleasant visual distinction between the project and the surroundings will improve acceptability by the tenants and the community.
6. Allocation of space between dwelling units and communal areas will be more acceptable to the users if they are involved in this planning.

User needs hypotheses to be tested include:

1. Involving the community (e.g., model neighborhood organizations) in the development decisions will result in greater acceptability of the dwelling units and the project.
2. Involving the members of the user groups in the planning process as "non-professional" planners will result in greater acceptability of the project.
3. Involving indigenous labor in the construction process will result in greater acceptability of the project to the user and the community.
4. There is a difference in acceptability of projects based on the sponsors' backgrounds and origins.
5. Tenant advisory groups can assist in housing management and improve acceptability without increasing housing management costs.
6. Returning unused balances of operation and maintenance reserves will improve tenant responsibility and result in lower costs of operation and maintenance.

There are currently developed technologies for the high-rise dwelling construction which can reduce costs of this type of building while meeting the needs of the users. Technical innovation could be used which would permit testing the following hypotheses:

1. Offsite factory-produced structural shell units can be provided at final costs equal to or less than those of current construction with more efficient use of labor.
2. Indigenous labor can be used in the production of the housing components at competitive costs.
3. Incentives can be found to reduce labor union restrictions to new technologies and indigenous labor.
4. Methods of approach to code authorities can be developed to remove code constraints.
5. The use of an industrialized technique will reduce the impact of seasonality on the work force with a consequent reduction in cost.

Technological schemes which could be considered for this sub-experiment include a number of structural systems such as the Balency and Bison reinforced precast concrete systems and several service system concepts including unitized bathrooms, plastic piping and total energy systems.

There is a procedural and legal hypothesis that can be tested: By obtaining HUD/FHA approval of a procedure for minimum certification, the processing time for a housing project can be substantially reduced.

The foregoing is one of the typical problems to which the In-Cities Experimental project will be addressed. There are other high-priority problems which will be included in the project. The user needs, constraints, innovations and eligible cities to be tested as part of the expected solutions to the problems have been tabulated and organized into various matrices which lead to priorities and levels of importance for their inclusion in the overall project.

The first step links together three sets of key input variables and a set of possible locations. The input variables are:

1. Specific groups of lower-income users in urban areas who are most in need of improved housing, i.e., large black families, elderly families, medium-sized Spanish-speaking families, etc. The groups were further defined on the basis of family size, position in the life cycle, and income level. The basis for priority ranking is population level, urgency of the group's housing need, and the likelihood of the need being met through use

of existing means, that is, the degree of need for Federal assistance.

2. Basic building types and dwelling unit densities, referred to as "vehicles", i.e., detached houses, attached houses, low-rise apartments, etc. Both new and rehabilitated housing is included. Each vehicle is assigned an applicability rating according to the degree to which it meets the needs of each user group.
3. The most severe constraints inhibiting the introduction of innovation to production of each type of lower-income housing in urban areas; i.e., building codes, labor practices, financing, use of indigenous labor, etc.

Subsequent steps use each set of input variables to generate a series of potential sub-experiments that would provide information vital in rapidly expanding production of urban housing for lower-income households. The sub-experiments concerning user groups provide data on how to serve their needs better, lower the costs of doing so, and raise the acceptability of the resulting housing to its occupants. The sub-experiments concerning basic vehicles involve technological innovations in building design and techniques aimed at the same objectives as for the user group sub-experiments. All sub-experiments will involve constraints and, thus, will provide data on how to counteract them, therefore cutting housing costs, accelerating production time, and increasing the acceptability of lower-income housing to the users and the community. The locations are the specific cities in which a given sub-experiment is needed and can be performed effectively and rapidly.

The synthesis included a process of selecting specific items from each of the above types of sub-experiments and combining them into "experimental clusters." To do this a matrix was prepared with the user groups and their rank as rows and the vehicles with their applicability ratings as columns. Each intersection of row and column indicates a potential experimental cluster, and a multiplication of the user need ranking by the vehicle applicability factor gives the priority rating of the cluster. Each cluster contains an internally consistent and interrelated set of sub-experiments that will provide useful knowledge about all three types of input variables (user groups, building types and constraints), usually including several technological innovations and several constraint-reducing innovations. The entire set of experimental clusters will provide a significant test of all the sub-experiments likely to prove most effective at ameliorating constraints, better serving user needs, and testing the effects of technological innovations.

The method to this point has enumerated the potential experiment clusters and has given each a priority.

The next task was to match the cities to the combinations of user groups and vehicles. This was done by the use of another table which rates each city as to its appropriateness to the user group-vehicle combinations; those combinations having a low priority rating are discarded. The city ratings were based on the degree of interest in the city in lower-cost housing, the city's capability of supporting an experiment, and the degree to which significant impediments to the construction of lower-cost housing exist in the city.

Specific sub-experiments are next designated for the purpose of testing the acceptability by the users of the various aspects of housing for lower-income families. These are concerned with what seem to be misfits between present housing approaches and lower-income user needs and aspiration. These sub-experiments are organized in two groups:

1. Those which generally apply with distinct priorities for the various user groups, and are therefore subject to ranking. They address problems of planning and design.
2. Those which generally apply with very little difference in priority between the various user groups. They are concerned with problems of the project development process and housing management.

A matrix has been prepared tabulating the user need experiments against the user groups. A low-medium-high ranking is established for each of the sub-experiments, rating its applicability to each of the user groups.

A list of constraints applicable to the user needs and aspirations is then prepared which ranks the constraints as low, medium or high levels of importance. Finally, a set of sub-experiments is designed to explore methods of relieving each of the high-level constraints such as community attitudes and willingness on the part of the user to assume some degree of operating and maintenance responsibility.

The final tool needed for carrying out the process of establishing the experimental program is a summary tabulation prepared during Phase I, which lists all promising building innovations and relates

332-247 O - 69 - 8

them to vehicles to which they can be applied with the highest potential cost saving.

At this point, the following tools have been created:

1. The overall priority ratings of potential experiment clusters
2. The sub-experiment relationships which are:
   (1) the user needs experiments related to user group by priority
   (2) the constraint-related experiments and their priorities
   (3) the tabulation of innovations rated as to their applicability to the vehicles and user needs and aspirations
3. A city group selection table.

The use of these tools in the complete definition of a sub-experiment may be summarized as follows:

1. Select a first order problem, such as how to rehabilitate housing on scattered sites on an economical basis.
2. Select a small set of compatible first order innovations (such as vest-pocket urban renewal covering an aggregation of scattered properties) which specifically address the problem.
3. Identify the first order constraints such as administrative procedures which inhibit the application of each of the innovations.
4. List candidate cities, i.e., cities in which
   (1) This problem exists
   (2) These innovations have not been tried, or have not been successful, because of these constraints
   (3) The administration wants to solve the problem
   (4) The internal conditions do not pose city-specific constraints which cannot easily be removed.
5. Identify the user groups (ethnic, family size, income, etc.) in each city most in need of housing.
6. Identify the building types and project types (vehicles) most appropriate to the city and most applicable to the user groups.
7. Select a city, group(s) and vehicle(s).
8. Identify second order problems, such as inspection of a pre-fabricated unit assembled in another city.
9. Develop second order innovations, such as acceptance of the assembling city inspection by the receiving city for the material in Item 8.
10. Identify second order constraints, such as resistance to Item 9.
11. Reiterate Steps 7 through 10 for all cities listed in Step 4.
12. Reiterate Steps 1 through 11 until all first order problems have been covered.
13. Screen sub-experiments for balanced inclusion of user groups, vehicles, first order innovations, first order constraints, cities, sponsorship types, etc.
14. Redesign sub-experiments as necessary to obtain balance and favorable cost-benefit ratio.
15. Submit to HUD with recommendations.
16. Select cities (HUD).
17. Negotiate with cities—(Kaiser Engineers).
18. Reiterate steps 8, 9, and 10 as necessary.
19. Design city-specific procedures for implementation.

When the series of sub-experiments is believed to be complete, three checks are made:

1. A check of the number of cities with high appropriateness rating which have been selected as sub-experiment locations, compared to the total number with high rating
2. A rough cost of the total construction program
3. A check of the high-priority sub-experiments to determine how many of the high-priority user needs, constraints, and innovations have been used.

Finally, an overview judgment is made as to whether some really relevant and important sub-experiments have been omitted, or some others of a lesser level of significance have been incorporated. Some "cut and try" adjustment can be expected to be made which will increase the scope of the experiments or reduce their cost without reducing the total project scope.

The experimental program as a whole will have a set of resources—personnel, material, money, time—and a complicated set of interrelated activities which together will comprise the system for performance of the program. Since the activities all have a duration, have precedence relationships to other activities, are subject to certain constraints, and consume a set of resources, they can be ordered into a network and a chart of accounts, and can, thus, become the entity around which the project data base will be organized.

This project data base will satisfy the three major aims of the information system effort:

1. assistance in "real-time" project management
2. the development of a data bank for the performance of specific analyses of the impact of constraint variations in the sub-experiments
3. the base from which acceptable extrapolations can be made from the low volume of the sub-experiments to the necessary high volume of the national requirement.

The basic premise is the use of ordered activities linked to an account ledger as the primary entity around which the data base is organized. The program is made up of three separate and distinct phases:

1. a planning phase
2. a scheduling phase
3. a data collection monitoring phase.

The scheduling phase begins when the plan for accomplishment of a sub-experiment has been developed and the input data that describe the plan have been produced. At this point a numbering system common to both scheduling and costs is devised and schedules are generated in formats as required for various purposes.

The third phase is the one that (a) enables project management to keep up with the project as it is being executed, and (b) creates the data bank needed for the sub-experiment. Management data will describe new activities, delete activities, change activities, record the work performed, and record changes in the projected job quantities, man-hours and costs, the status of open commitments, procured items, etc. This information not only allows the project manager to control the project as it is being executed, it also enables him to measure the effects on the schedule of proposed changes in plan. Separate from project management is the need for processing the experimental data. Data on construction and operating costs, and all other statistics which are to be analyzed to establish the results of the sub-experiment, will be processed as needed prior to analysis. All information collected will allow the history of the entire project to be reconstructed in as much detail as deemed necessary and useful.

Kaiser Engineers has been working for several years with various integrated computer control packages and has used them successfully on a number of large projects. These systems are currently being expanded to form the basic structure for a large part of the "In-Cities" information system. Using interlinked programs and files, the latest package includes routines for scheduling work, measuring physical progress, cost reporting and comparisons of cost to budget, productivity analysis, procurement and processing status, force reports and management reporting and analysis.

Additional data files will be needed for the information pertaining to social experiments concerning acceptability and user need. These files will be used to compute descriptive statistics such as means, variances, correlation coefficients, etc., which can be subjected to various analyses. Definition of the requirement for this type of data is proceeding and its relation to the information system will be established following this definition.

On completion of the selection and adoption of the experimental program, the tasks of implementing it must be accomplished. The first general task will be to prepare what might be called a prospectus which described the overall experiment and sub-experiment objectives and plans. It will specify the general size and configuration of the structures, the type of construction, building technology innovations to be included in the detailed design, typical unit floor plans and other details of the physical aspects of the plan. It will also outline other facets not directly concerned with construction, such as financing, and the management system to be used for operating the completed project. This document will be used at the outset of implementation of a sub-experiment plan to explain to city officials, citizen groups, potential project sponsors, etc., what the sub-experiment is and what it is designed to accomplish.

Kaiser Engineers and HUD will assist the city in its selection of a sponsor (hopefully indigenous to the area in which construction will take place). When the sponsor has been selected, specialists from Kaiser Engineers' team will be made available to the sponsor to provide needed assistance in site acquisition, obtaining financing, selecting the architect and construction contractor, obtaining permission to use building innovations which do not comply with existing building codes, and all other aspects of the task of accomplishing the work. We will also provide assistance to the sponsor in organizing the operating management of the completed facilities and in monitoring the results over a reasonable period after operations begin.

It is anticipated that some sub-experiments may be subcontracted either in part or in their entirety to interested industrial firms, such as a firm who produces a major building component or system that is to be incorporated within a specific sub-experiment.

For the duration of the project, close monitoring of each sub-experiment will be maintained to assure that the sub-experiment will be effective in meeting its objectives. Procedures established for change control will examine any proposed sub-experiment change for its effect on the entire experiment before the change is effected.

Finally, when data are complete for any sub-experiment, analyses of costs and benefits will be made for both technical and social elements, and overall conclusions and recommendations documented in the final reports for the project.

The timetable is to begin construction on some of the sub-experiments in the Spring of 1969 and to have construction complete on all sub-experiments by the end of 1970.

This is a big project, an important project, and the first controlled experiment in housing conducted "in-city" on a national scale. It is devoted to the greatest national housing need—that of lower-income families. Not all of the sub-experiments will lead to lower-cost housing that will have successfully removed constraints and satisfied user needs. But most of the sub-experiments will be successful in those respects and on that basis, this program will be a very important part of HUD's charter to improve significantly the manner in which the people of the United States are housed.

THE ROLE OF THE PERFORMANCE CONCEPT IN URBAN SYSTEMS

Terry Collison

Relation to Other Conference Themes

By this point in the conference we have heard and discussed the impact of the performance concept at a couple of different levels or scales and for several different applications. We have talked about the performance concept in relation to building materials, in relation to building components, in relation to systems within buildings, and in relation to the organization of many systems within a complete building.

One presentation—and I personally attribute great significance to its inclusion in this kind of meeting— focussed directly on users, their needs and role within a performance context. Since performance requirements derive ultimately from the needs of users, it is ironic that it seems so easy to lose a consciousness of the user when we start examining alternate ways of actually delivering performance.

Materials and hardware systems are things we can manipulate. Users and meeting their needs are the objects of the manipulation. We hope that we can serve them by the way we use materials to enclose space in buildings and by the quality and arrangement of various life and activity support systems.

This is a more or less neutral performance objective: to provide service and performance to the level of user needs. Yet the relation between performance and need is hardly ever so finely tuned; one usually exceeds or falls short of the other. Much of the incentive now for a performance orientation—at this conference and in fact generally—grows out of the realization that performance capability commonly does not measure up to needs. Against this background condition, the neutral performance objective seems a thoroughly positive one.

But user activities and needs can also be influenced by the performance structure in which they are exercised. That is to say, user activities and needs can also be manipulated. True, the nature of this manipulation (or influence or effect, if that seems a more comfortable word here) is inexact, imprecise, and often indirect. But it is a factor. The way space is enclosed and services conveyed influences the way people behave and the benefits they derive. In the negative situation, where performance capability exceeds immediate user demands on the system, then personal and social growth and development can occur.

This is a restatement of themes presented in many different ways in previous sessions at this Conference. We are now going to talk about the performance concept at a new and somewhat unfamiliar level. We are faced on the one hand with the basic complexity of urban problems and the seriousness of current disfunctions within various urban systems. Yet at the same time we cannot fail to recognize both the potential for life in cities and the dynamics of metropolitan expansion and regeneration. Given a sense of both the problems and the potential at this level such a restatement offers a good basis on which to begin this presentation. It establishes a context for the concepts I want to set before you and for the discussion which I hope will follow either here or informally later.

I would like to discuss the following items:

I would like to start by briefly examining the nature of urban systems as we will be talking about them.

Next, I would like to give examples of urban systems which I think it useful to discuss within a performance context.

Third, I would like to refer to an analysis and design procedure for handling the requirements within individual urban systems and for responding to common or conflicting performance requirements that may exist between two or more systems.

Fourth, I think it important to point up significant themes and implications that grow out of a performance orientation to urban systems and to the problem of planning, developing, and operating them.

Finally, I would like to identify three directions for further research and test applications of the performance concept in urban systems.

The Nature of Urban Systems

There are various ways of slicing up the urban community into systems. We have all done this either perceptually as we identify the transportation system in which we ride, or logically as we attribute systemic characteristics to something like housing which most of us really know directly only by its individual physical units.

These examples are plausible enough yet at the same time there is something intriguing about them. For example, in speaking casually of the transportation system, it seems somehow more natural to use the word "ride" rather than the word "drive". Even with its current state of generally less-than-satisfactory performance, the "ride" type of transportation—rail, bus, subway—seems perceptually more like a system than the drive-type of facility—highway, arterial, collector road. Physical identifiability and specialized use are factors here I believe. The key word, however, may be "seems", for physical identifiability and special use functions are probably not what determines whether something is or is not a system.

In the second instance, the housing system, we speak comfortably about a phenomenon that can be conceived as a system only if we include the associated operation of financing mechanisms, legal instruments, marketing programs, building and development regulations and a series of related activities, none of which inheres in the physical object, the house, which is the product of the system's functioning.

There is a parallel case in the transportation system. It is easy to identify the transportation system as the buses, the trains, or the subways that move people about in a metropolitan area. It is easy, too, to include bus drivers and train engineers as part of this system, but more difficult to include such disparate things as change-booth personnel, elevators in office buildings, or street signs. Not impossible, certainly, but simply a stretch of the imagination as these things fill a role that is further removed from what seems to be the major objective or purpose of the transportation system.

On reflection, however, it is clear that the ability to move people and goods within an urban area would be seriously impaired by the lack of these additional items. To the extent that they enable "transportation" to occur, they must be considered part of the transportation system. (It is important to realize that one of these elements may act as part of other systems as well. For example, street signage may well be considered part of the communications system with respect to the problem of delivering mail. And the requirements for the two different urban systems may be dissimilar.)

Through these examples we begin to understand something about urban systems and the concept of performance in relation to them. To bring this into focus we should consider the following five contrasts:

A partial versus an expanded concept of an urban system
Public versus private system responsibilities
Hardware versus software system attributes
Service-oriented versus product-oriented systems
Operating versus development systems

The example of the transportation system and the housing system reveals something about the way urban systems are commonly perceived and identified. Urban systems which are perceptually obvious tend to be only individual elements of the structure or process that is the real system. We note, for instance, that only certain aspects of the total movement apparatus in an urban area are commonly regarded as "the system". There is both a bias for some modes over others and an incomplete inclusion of ancillary but still necessary system aspects for any given mode.

If the transportation system is an instance where the casual or immediate conception is a partial one (including some aspects and ignoring others), the opposite is true of housing. Although there are many systems within a house, there is nothing especially systematic about the physical inventory of "housing" at the urban level. If one wishes to speak of the housing system (and there are several valid reasons for wanting to do so), he must include the operation of the other institutions we cited earlier. This is a case where the concept of the system must be expanded beyond its initially obvious elements or its apparent product.

The second contrast is between public versus private system responsibilities. It may seem that the dominant characteristics of housing are private. Although this dominance may or may not prove true after more detailed analysis, there is no urban system which comes to mind that excludes one or the other sector entirely. The public role in transportation does not in itself qualify the activity as an urban system any more than the apparent

dominance of private responsibilities in housing precludes it from being considered an urban system.

A third contrast, that between hardware and software system attributes, is a similar case. The urban transportation system may have a very high investment in hardware while some other urban system, like social services, may have almost none. It seems to me that this is not significant here. The education system, while having a substantial hardware component, nevertheless is characterized by its software aspects. Hard and soft distinctions may be useful at some level of analysis, but again, not as prerequisites for an activity being considered truly an urban system.

The fourth contrast is between activities having service as their output and those having tangible products as the result of their operation. The problem in drawing distinctions arises in something like the education system where the output can either be considered as a service (development of an individual's abilities) or as a product (either the skills that are developed or the people that are trained). The distinction may well have implications for the way a system is operated (to maximize a service aspect or a product aspect), but it is not significant in distinguishing urban systems from non-systems.

Finally, we consider the case of operating systems in contrast to what I have labeled development systems. This is probably the most significant distinction of the five. Transportation as we know it is essentially an operating urban system concerned with providing service through the commitment of resources within an existing structure of institutions and hardware. By contrast, housing is most often thought of as a development oriented system concerned with generating a new inventory of shelter in metropolitan areas.

These examples would imply that operating systems have a service output while development oriented systems have a product output. I think this distinction is tied to the fact that the qualitative and quantitative demand on the urban housing system is currently more dramatic and even critical than is the demand on the urban transportation system. By contrast it is possible to consider a time when a major purpose of the urban transportation system will be to create new quantitative and qualitative circulation capacities or when the housing system will operate essentially to meet balanced internal demands, well understood housing needs, and perhaps minor population shifts.

There is a clear difference between operating systems and development systems in terms of goals and the way each is administered and run. These differences, however, seem to be a matter of degree rather than of fundamentals. As performance demands on an operating system increasingly exceed the delivery capacity of that system, then pressure accumulates for it to take on some degree of development orientation.

The lessons learned in examining these contrasts say something about a valid definition of an urban system. Rather than defining urban systems conventionally by the institutions which have evolved over time to meet needs in the community, it is now useful to re-examine the various areas of need as they currently exist. Since needs shift over time and since new needs can develop, the pattern of existing institutions may not correspond to the present pattern of needs.

Institution-based systems tend to perpetuate themselves by continuing to value and therefore recognize the type of need which originally brought the institution into existence. It is precisely because it can transcend the limits of individual existing institutions that the performance concept is so valuable when applied to the urban or community level.

Instead of starting with an institution and identifying what it does, an urban concept of performance starts with what is produced and from it infers the existence of a production system. An urban system, therefore, tends to be (a) functionally oriented rather than institutionally defined and (b) generic in nature rather than limited to any particular means of delivering desired performance.

The Relation Between Urban Systems

In Figure 1 is a matrix with a listing along the left side of 27 operating urban systems.[1] Figure 2 describes these 27 urban systems and reading down this list one can quickly get an impression of the functions that have been singled out. You will note that the matrix is predicated on a simple input-output model. A number of resources are fed into a transformation process whose nature is inferred from the resulting product or output that occurs. You will note also that both direct output and indirect or "waste" output is generated by the operation of any of these systems. Of course the waste output is not literally useless but represents

[1] This conceptual framework has been developed by Professor Richard D. Berry at the University of Southern California.

DEVELOPMENT SYSTEM

"ENVIRONMENTAL DETERMINANTS OF SYSTEM CHANGE"

OPERATING SYSTEM

27 OPERATING URBAN SYSTEMS

	G	H	I	J	K	L
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						

FIGURE 1. Matrix.

either slack utilization of the input resources or an incidental output of the system.

There is nothing magic in the number 27 and there is generally nothing magic in the titles that have been set to the system. In fact, some of these now seem unfortunate choices. The basic idea, however, is reasonably clear. All 27 urban sub-systems together form a fully functioning com-

FIGURE 2. Operating Urban Systems.

munity. This is taken to be a more-or-less "closed" system in itself, with the output from any given system used as an input for some other system or systems. This pattern corresponds to the familiar biological and economic concept of efficiency or conservation.

The reader is asked to do some visual and mental juggling at this point. In Figure 2, the list of 27 operating urban systems will be the left-hand, or vertical portion of the matrix in Figure 1. Figure 3, here called the Functional Definition of Community Development System starts at its left side with a list (vertical column A) of six input parameters. It is these six "Environmental Determinants of System Change" which form the horizontal portion of the matrix in Figure 1.

The other kind of system—the development system—can also be illustrated (Figure 3). Here the objective is, as we mentioned earlier, to bring a new structure into being, or perhaps to reorganize an existing operating structure. This particular model is couched here in terms of community development but is also applied to various individual elements of community development as well. Housing is a case in point. Housing is an organization of performance capabilities that can be described in terms of elements in this model. Sub-system #24, the enclosure system for the community, provides settings for residentially-based activities as well as for other kinds of activities. In addition, the enclosure subsystem interacts with many other urban subsystems, among them numbers 2, 3, 7, 15, 16, 19, 20, 21, and 25. The degree of dependency varies from case to case, of course.

Finally notice that there is a linkage between the development oriented system and the 27 operating systems. The six-way grouping of descriptive factors occurring along the left hand side of Figure 3 also appears across the top of Figure 1. This enables one to describe the creation or establishment of any given operating system in terms of the basic development model.

This can be quickly illustrated and summarized with reference to sub-system #25, the Population Transportation system:

The Population Transportation system is a function of government regulatory structures and is sometimes itself a government service.

It is a function of available capital financing and contributes to public revenues through the taxation structure.

It affects the structure of property ownership along rights-of-way. It responds to the structure of property use and precipitates changes in that structure and its levels of intensity.

In theory the transportation system should be responsive to socio-economic growth and to various kinds of social and economic interchange.

The transportation system must respond to the geography and physical structure of the land and its pattern of development.

Finally, it is obvious that the kind of transportation systems we build will be a function of available construction technology. In the case of the transportation system, such a limit is particularly unfortunate at this time since the evolution of applicable transportation technologies has tended to lag behind urban circulation needs.

Role of the Performance Design Procedure

With this understanding of urban systems and the outline of their interrelation, I would like now to refer to the idea of a performance design procedure as it is applicable at this level. The characteristics of this procedure may shed additional light on the areas we have discussed so far.

There are five general steps in the performance design process:

First one must establish the design objectives or performance goals.

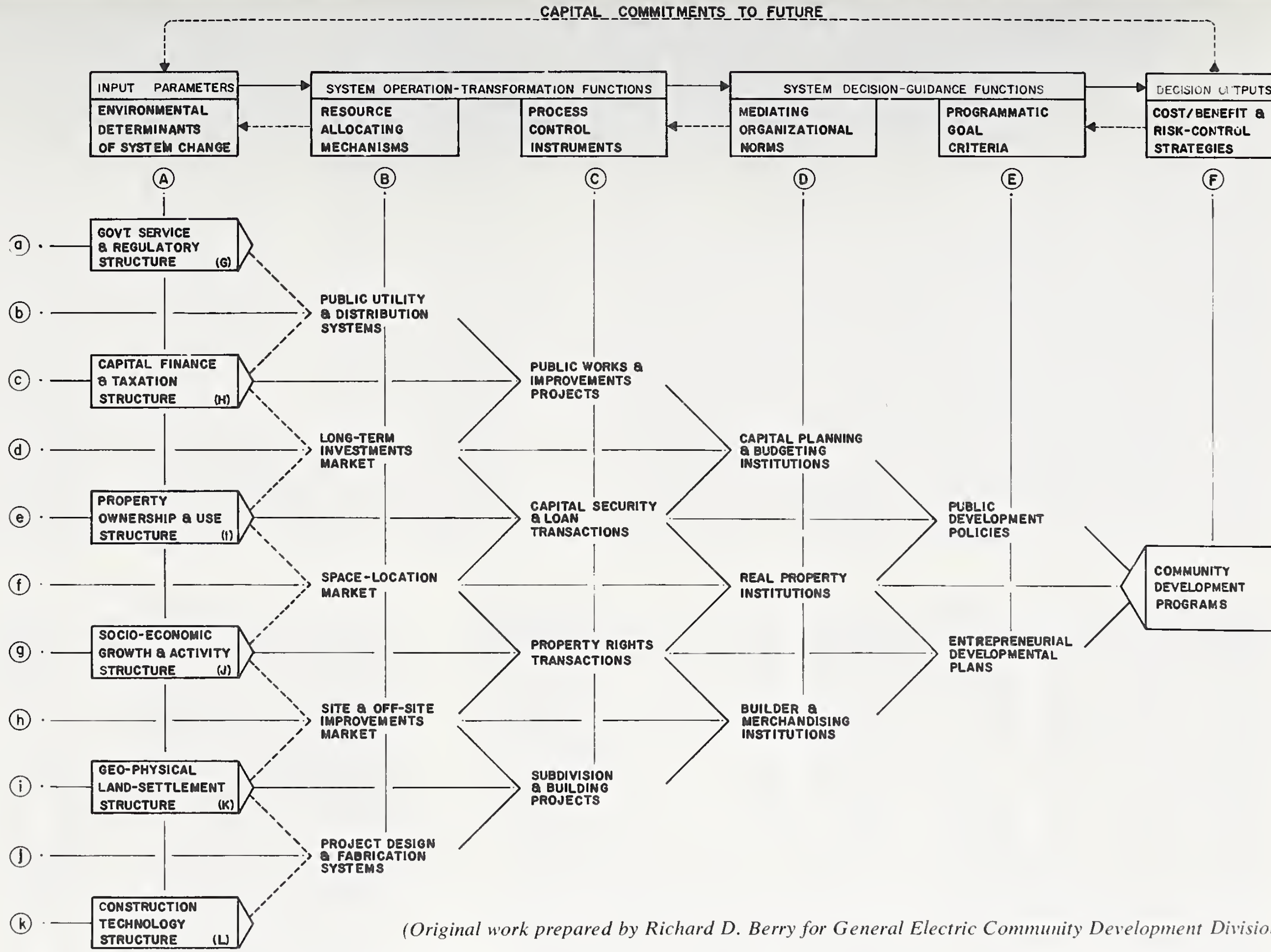
Next, he must identify the design constraints or limits within which these objectives must be realized.

Third, there must be some method for applying the performance objectives within these design constraints. Currently this question of design methodology is the subject of extensive interest within the design field.

The fourth element is simulating and measuring the performance potential of alternate designs.

The final step is a revision of design in light of this measurement and the feedback process.

These last two steps, of course, are found not only in the design phase but in the operational phase as well. In such an extended design process, performance—either actual or simulated—is used to measure alternate designs against program objectives and as a basis for revising and altering delivery systems in order to maximize performance objectives.



(Original work prepared by Richard D. Berry for General Electric Community Development Division)

FIGURE 3. **Functional Definition of Community Development System and Heuristic Structure of Research-Planning Model.**

The Diagrammatic Lattice of Labeled Attributes Describes the System's Structures in Two Ways:

(1) Reading from left to right in sequence, each attribute in a given column-row can be viewed as a class of events which is defined conditionally by the intersection (or meet) of the two classes of attributes in the preceding column: e.g. if B–b and B–d meet (or intersect), then the resultant is defined as C–c, (or) $B_b \cap B_d \rightarrow C_c$.

(2) Reading from right to left sequentially, each attribute can be viewed as a set of macro-functions with any given set progressively defined by pairs of sub-sets in subsequent columns: e.g. E–e is a function of D–d & D–f, (or) $E_e = f(D_d, D_f)$.

Design methods for urban or community systems have been developed and expanded upon elsewhere by myself and others. If some of you have a further interest in this particular area, I can direct you to and additional discussion of this.[2] What is important for the present discussion is the idea behind this design approach—namely—

1. to lay out the limits within the entire design problem,
2. to identify requirements, their influences, and their limiting effects,
3. to identify all points where design alternatives may exist,
4. to generate the alternatives for each point,
5. to explore the overall implications of selecting each particular alternative, then
6. to optimize performance objectives throughout this network of design alternatives.

This approach is in marked contrast to the conventional way design is done.

Often the limit in the conventional process is that design investigations occur in a sequence of discrete steps. Generally there is little chance to adjust a previous decision in light of subsequent insight without thereby undermining the value of all other design decisions which are conditional on the original sequence.

By contrast the systems design approach asks that a resolution between design alternatives not occur until the moment when it actually must occur, and then only after conscious evaluation of all the alternatives and their larger implications. With its emphasis in expanding sets of design alternatives rather than closing them down, the systems design process may actually identify alternate ways to meet urban performance objectives through several different operating systems or a combination of them.

Themes and Implications

There are several significant themes and important implications that follow from the distinctions we have drawn.

It seems to me that it is at the level of urban systems that a number of the other performance capabilities which we have discussed here at this Conference come together and thereby fall into some kind of overall relationship.

It is at the level of urban systems that some of the performance implications for building components and building service systems may start to bump into one another and conflict in a meaningful fashion.

Because the effect of such conflicts is so diffuse, their resolution will frequently depend on conscious policy decisions. At the level of urban systems such policy decisions can be especially significant. Consider, for example, the implications of such relatively clear issues as dimensional coordination for materials or performance-based specifications for plumbing systems. Here the lack of "fit" occurs between hardware items in building systems, aggregated and considered at the urban scale.

Let us also consider a conflict directly involving performance requirements and delivery systems at the urban level. At this point in time the institutionally defined city school "system" and the performance defined urban education system frequently seem related to one another only by history and imagination. To many who participate in the institution, school seems irrelevant to life as they know and must live it. To detached analysts who are interested in the delicate problem of personal development, the institution often seems not only irrelevant to life, but hostile to personal development regardless of the area in which it might actually be able to occur. The school system is not the only institutionally defined system against which this kind of criticism can be leveled, of course.

Education, even considered as the formal learning process, takes place not simply in school but in other contexts as well. One of the easiest cases to illustrate is homework—part of the formal learning process that occurs in an institution other than the school. If the home environment is so overcrowded and noisy that homework cannot be done thoughtfully, and if, in fact, it is important that homework be done thoughtfully, then either (1) the education system will have to compensate for this disfunction by altered programs, (2) the education system will have to amend its performance objectives to be consistent with the performance constraints (the home environment among others) or (3) some other system will have to bear the cost of the education system's unmet performance objectives. The principle of conservation within a closed system, rather than being obscured and disguised,

[2] Terry Collison, Systems Planning for New Communities; A presentation to the AIA/ACSA Seminar on "The Impact of Industrialized Building on Architectural Education" (The American Institute of Architects; September, 1968).

is now made clear. Although this may seem to emphasize a massive and rather serious failure, I feel it to be essentially a positive step.

We now recognize that learning is something much more (and much less) than what formally occurs inside the walls of a school building. It is a phenomenon that may well involve the standard school trips to the zoo and visits to the local art museum but it runs well beyond these too. A performance concept of education would measure the effectiveness of a formal learning system by whether educated people are actually produced, rather than by such secondary indices as student-teacher ratios, spending per pupil, new facilities per year, or racial ratios. One suspects this performance approach, particularly with respect to education, would be brutally honest. It would indicate the true cost of not delivering required performance by measuring the marginal costs that would be incurred as disfunctions in other systems.

This concept of inter-system tradeoffs and impacts is a rather complex modeling problem, certainly, but the performance concept offers a basis for continuing to work on it.

Next Steps

In addition to the need for orienting planning and design education along performance lines there are three directions for further work that are clear at this time.

First, it is necessary to expand on characteristics of the 27 operating urban systems. Of interest is the interaction between various operating systems as well as that between any given operating system and the development process which would bring it into operation. These linkages are admittedly complex but in the end will probably seem less so than the way we currently proceed to plan and to design urban systems without a clear understanding of the relationships.

Secondly, it appears very important to evolve ways in which a diverse group of people having various design resources can participate in a performance-oriented process for designing urban systems. Here we would attempt to program how architects, planners, economists, sociologists, management specialists, and others could best interact in a performance context. The performance concept offers a way to deal with the component design problems lying within a complex performance profile such as is found in urban systems. At the same time it appears to offer a way to establish design responsibilities in a team which derive from the characteristics of the problem and not from the artificial divisions of academic or professional disciplines.

Third, it is vital to apply the urban performance concept to the solution of real problems. A sequence of decisions and investigations which may appear logical when originally programmed may turn out not to correspond to the structure of an actual design problem. This can be learned only by feedback from a real design situation. There are several especially useful problem areas in which this concept can be applied—new community planning and development, major urban renewal projects, planning and development of individual major urban systems, (housing, transportation, education), perhaps Model Cities, and programs like HUD's current in-city housing experimentation program.

Conclusion

The area of performance design is currently marked by a reasonably good understanding of the performance concept but very little understanding as yet of actual structures for delivering and insuring desired performance. These structures can be evolved only through experience with designing real urban systems. Throughout this effort it should be remembered that the real issue in urban design is neither physically pretty cities nor complex problem models of great elegance. The real issue in urban design is performance—the performance of generically defined, fully functioning delivery systems for services in urban areas.

CONFERENCE IMPRESSIONS AND COMMENTS

William A. Allen

Bickerdike, Allen, Rich & Partners
57 Russell Square, London WC1

As something of a special guest from afar let me take this, my first public opportunity, to do some thanking. First it must be to Mr. Eberhard himself, and to Dr. Wright, for the opportunity to participate in this new building research activity at the Bureau, then to Dr. Kushner for his original and continuing interest, and to Dr. Walton for including me in the Conference program. These and many others have made me their proud friend.

Now to business, and I begin with some impressions.

We have had elegance, led off by Mr. Eberhard's valued paper. There has been vividness and wide scope, ranging through the spectrum from the tactical detail of Mr. Robinson and Mr. Achenbach to the larger strategy of Mr. Bush, Mr. Collison and Dr. Wright. And there has been depth in the discussion of the derivative philosophy, vital in the early development of such an idea as we have been examining. Dr. Walton and Dr. Cadoff have structured the Conference with great skill.

Mr. Eberhard and Mr. Brill identified the situation; we sense a gathering momentum of change. As Mr. Brill said, "It is an evolution so rapid as to be a revolution."

In this situation, comprehensive research is essential. There is no opportunity for feedback in conventional ways from ordinary experience, which formerly could correct the mistakes we make before they went too far. Now instead we have to observe accurately and analyze and feedback quickly.

There are always people in the world who hope that the pace of innovation and development will not be too great for them to cope with, but there is no safety today in standing still. I think one ought to be quite clear about this. Whether in the last few days here, or elsewhere in these last few months or years we have accurately defined the changing situation is not important. We won't know for ten or twenty years whether we are in fact seeing it absolutely correctly; but we can say this much confidently, that there is no safety now in avoiding change.

One particularly relevant point is the tremendous capacity today of industry and of organizational techniques to do vast things rapidly. It is the pace-maker of our situation; and it underlines why we need rapid and accurate feedback, because we can make bigger mistakes so rapidly. This is only possible now by the techniques and methodology of science and we therefore have a situation which is created by science and scientific technology which can only be managed by science and scientific technology. You can build wrong things today just as rapidly as you can build right ones, but they can be much bigger than before; so urgency is upon us, and the stage is set.

We are dealing with performance specifications as a concept and this is no isolated fragment of the present situation; it is central to our means of dealing with it. Performance specifications are a statement of what is needed, a statement about the market. If the building industry, in which I include its component makers and the relevant professions, had a collective capacity to order a market research, it would have to order something like what we have been discussing these last few days. And this seems to me to identify the character of the concept very clearly, not only for the many individual industries who make up the building industry, but for the building professions as well. But this is just another way of saying again that we have to deal with a situation which we have to monitor, for our individual needs and for the larger purposes of social management of a great nation's affairs.

So I say that if industry had the collective capacity to ask for what is urgently needed to confront today's situation, it would ask for what we are talking about. But the operation today is so big, it involves such a vast industry, it involves such a vast country, it is so fundamental to the welfare and economy of nations, that industry cannot in fact, do it alone. It cannot just commission it like that. Government cannot stand aside, nor can government do it alone, as Mr. Bush pointed out. It is inevitably a joint operation.

The people of the country and their well-being, and the economy of the country is at stake in mat-

ters of this kind. We are dealing with what is collectively the biggest industry in the country, and since this is the greatest country in the world, we are dealing presumably with the biggest industry in the world. But in this situation, there are a number of very unexpected peculiarities for which we have to be on the watch. We have to be able to confront some of them with intellectural courage, because they may cut across our conventions.

The client, in this case is the people involved. We are creating an environment as Mr. Eberhard said, "for peoples' ordinary human activities;" and as Mr. Mitchell added, "It is the non-verbal mass of the people with whom we are dealing." In this room we are a collection of relatively intelligent human beings. We are verbal, literate, numerate. We can express our views and we have means of expressing our views to places of power.

Very large numbers of people have no such capacity to express themselves, collectively or individually, and this is where we have to confront a new kind of social situation. We are committed to providing adequate living conditions for huge numbers of people whom we designers, manufacturers and builders will never meet except by accident. We can't go along to them individually and say "what do you want?" We have to discover what these clients' needs are by the processes of science.

Now in a great many cases, as we have seen, we are developing criteria, frequently new criteria or criteria more accurately specified than formerly, and we use the methods of science. But has it ever struck you, that in many cases we simply have not yet got the tools of measurement? Think of all the things which you ask for in a building design.

Suppose for example that you have got a sophisticated client in front of you. Perhaps he wants a concert hall, or something of that sort. He will say, well of course I want a successful concert hall, one that is going to be acoustically good for music, popular, with a sense of occasion. What is musically good? The people who are going to be critical about this are not only the audience, but the musicians as well. What does musically good actually mean to them? You say "I want warmth of tone;" but what are the physical parameters of warmth of tone? Critics talk about it but they have no means of expressing such things in physical terms. We simply don't know yet what warmth of tone is, or brilliance, or any of half a dozen such factors, even though they are what concert halls are all about. We have no means of going back and discovering what these things are, because we don't know what we are measuring and we have not got techniques for it.

There is in fact a general necessity over quite large areas of building technology to have tools whereby we can indirectly observe whether we have met our clients' instructions and their needs. And the more sophisticated the expression of the requirements, the more acute is the need to find some way of determining, for the purposes of feedback, whether or not we have met our clients' requirements.

Now I said a moment ago, as others too have said, that a dynamic state of affairs is developing. I said there is no safety in standing still, and in fact there is danger in doing so, for manufacturers, for builders, for professions. But if one cannot stand still, then it is vital to know where to go, and this too comes back to performance specifications, for they are supposed to be statements on everybody's behalf of where we ought to be going. I'm sure this point needs no elaboration.

Let me turn now to another aspect which seems to me especially important in this country. We recognize now that, despite the great achievement of a great many people in codifying and standardizing a great many things in which it is necessary to be systematic; one can't stand still, and the conventional code is a definition of a static state of affairs, the requirements of some given moment. As we see it now, codes and standards incorrectly devised, can add up to being a barrier to change. In fact, building regulations and building codes have often been the greatest barriers to innovations. They are intended to protect the public, but they can define together a situation about the market which can restrict what industry can profitably produce and offer to the public. If you write a code requirement that says a party wall must be nine inches thick, in brickwork, then you don't get very much opportunity for an innovation. If on the other hand, you say that it's got to have one hour's fire resistance and 48db. average sound reduction, (forgive me if I do not go into details) then you have something in the way of a performance statement, and this can be a real release of competition. And it becomes meaningful in the public and responsible sense, because we are competing to offer a variety of goods and services against known needs of our clients. In the ethos of America this surely goes to the root of its strength, that competition is the fundamental stimulus to service and invention. What

one is concerned about is only that the competition should lead quickly to good results.

So much then for performance specifications and my comments on them. You see I'm not summarizing anything in this conference; I so seldom do the things I'm asked to do, that I wonder I am ever asked to return. I'm merely commenting on things that came to my mind as we discussed our affairs these last few days.

Now, as Mr. Eberhard said, as Dr. Wright developed, and others have still further enlarged, the Bureau here is traditionally and centrally concerned with measurement. We have to understand, as Mr. Cullen reminded us, quoting Lord Kelvin, that "we only begin to understand when we begin to measure, and we only fully understand when we have fully measured." The uniqueness of our problem, and the uniqueness therefore of the Bureau's problem—and here they have almost a psychopathic problem—is that they have to begin to measure non-objective things. This seldom attracts scientists at first sight; how on earth to define and measure warmth of tone! They have to begin to measure people—their needs and their desires—more consistently and purposefully than has ever been done before. Sociologists have been working at this subject for ages, but often simply contemplating their navels, oscillating between observed situations and hypotheses, and back to observed situations to confirm the hypotheses, seldom or never going through the cycle of participating in building exactly what their hypothesis postulated in order to verify its validity. We have drawn boundaries in the wrong place around much of our research about building design, and around much of our practice. Because we are human beings we suppose we know what other human beings *en masse* want or need. It is arrogant of us, when we should be humble in our ignorance.

John Eberhard took us through a very elegant description of the increasing accuracy of measurement. I was fascinated by this. How the edge of the dot had to be defined more accurately because you found it was rough when you examined it closely. Then the dot was discovered actually to be composed of a whole lot of molecules—other dots; and then these molecules were found in turn to be composed of a whole lot of much smaller things than molecules. Indeed, in the end, these probably come out to be bundles of energy based upon probabilities.

Now, in fact, if you look at a family as a dot, this is what has got to happen to our study of it. This is what faces the Bureau, and it faces other people who are going to be involved in large-scale, low-income housing. The unknown household—we heard about the eight children and Mama who doesn't have a husband. We know something about the edges of such dots, but we now have to know much more about those eight children and Mama and what has happened to Papa, and we have to know much more of what kinds of living conditions they want or need.

There have been some useful statements about this. The gentleman from the National Association of Home Builders also said some very interesting things to me privately about what they had found to be the real interests of some families—the kinds of ideas they had about how far above their immediate social position they felt that they could aim or wanted to aim in their level of housing. There were certain things which were really important to them, and again certain things that they wanted only in their imagination. They separated them when faced with the real prospect of having them if they wished to pay for them. This is not too surprising, of course, but it is the kind of fact that should warn us not to project our own aspirations unthinkingly into the situations of others without study. We simply do not know a great deal about the kind of person I now have in mind.

I dare say that you, like I, occasionally look at the television and yet for the most part we do not need it to occupy our minds. We view selectively. Huge numbers of peoples on the other hand, have to have their minds filled from outside. The non-verbal mass of society are the people for whom we are in danger of misinterpreting things if we merely try to offer them what in our experience are our own aspirations or possessions. They may not be theirs. In fact they seldom are. We are ignorant about many housing needs, and ought to be energetic in overcoming this.

And of course it is not just the household; it's the collectivity of households that make a community. What is a community? As a bunch of do-gooders we build community centers. The real community center is likely to be the department store or shopping center. I imagine James Rouse is right about this.

A city is like a house and a house is like a city, and that dot of Mr. Eberhard's has got to be carefully explored. Another special aspect of performance specifications is the necessity to be both

332-247 O - 69 - 9

comprehensive and balanced, because it is dangerous to have gaps or to be out of balance. It's very simple: gaps and imbalance destroy credibility to the user. Everybody knows that there is very little point indeed of having a motor car that is designed with four wheels if you only have three of them. It destroys the credibility of the thing as a vehicle to drive; but as Dr. Wright said, we are frequently still at the narrative stage of measurement of our performance requirements; and as Mr. Achenbach and Mr. Robinson and others demonstrated yesterday, it still is exceedingly difficult to be comprehensive or even to know when you have been comprehensive, even in the single specification, let alone an area of performance specifications; and without being comprehensive you can't be balanced.

I remember when I was just a little kiddie in the Building Research Station in England, I had a very electrifying boss from whom I learned a great deal. He and I were out on a job once and he said, "Let us drop in on my father for the night; it will be simpler than staying at a pub." His father was then a rather elderly man. He had been a builder, and as a builder he had been very successful. He had built himself a very comfortable house, and among the things he had built for himself in this very personal house was a teak bathtub. He liked the idea of being in contact with wood. He liked its sense of warmth. He retired rather early that evening, and as we sat downstairs, drinking a little and discussing where we had been and what we had seen that day, there was a great crash from the kitchen. We rushed out there to find his legs dangling through the ceiling and the bath water coming down past them. He had forgotten one thing about his performance specification; he hadn't allowed very much for durability. So it is difficult to be comprehensive.

Seriously it is very important not to leave gaps and I would like to say—I would like to really urge—as an architect speaking now to my scientific friends: we don't want gaps left there because we don't know when they aren't there. It is necessary at least to identify them and include them even if it is only by narrative, or by speculation, or judgment, or by the roughest of measurements. Not all things can be measured equally well yet, and we cannot wait for them to be measured equally well.

I put this rather strongly partly, at least, because if one only describes what is well-measured, its solidity throws less well-measured things into such contrast that their real importance can easily be misjudged. What can now only be covered by narrative may in five or ten years be shown to be the thing that matters most. Before the war all lighting goals were higher numbers of foot-candles—a sort of foot-and-candle disease—because this was what could be measured and predicted. We could not evaluate and did not understand glare and visual performance, which we now know to be more important. This is a good example of what I mean.

For the professional man, this comes down to how robustly he can maintain his judgment in the face of the glaring power of science, and this is very, very important, because judgment is the basis of professional activity and responsibility. And it highlights this one danger of science—its strength and solidity. When a piece of knowledge is consolidated, it has the durability to last perhaps forever; but it's not the totality of a real-life situation. In fact we are not likely in our time ever to have the totality of knowledge laid bare by science—which is perhaps fortunate for scientists because they wouldn't have any jobs; but seriously, it is very important for us in the industry, and for professional people, and for scientists for their part, to recognize this danger that if they restrict themselves only to those things which they know, and don't even tell us of what they only think they know, then we may be very seriously misled, with the best intentions in the world. To the professional man or a person in industry a part-answer is no answer at all, and we ask for a special effort to step beyond the ethos of strict science, where one is concerned only with those things which have been established with certainty, into the world of speculation and narrative when these are the only means of bridging a gap.

So performance specifications may be uneven things for some considerable time, and I guess we all know it in the reality of our experience. But it is one reason why in some of the advice I was privileged to offer the Bureau in the development of its building research program, I expressed the hope that they would be able to establish a fine mix of professional and scientific and industrial minds, because it is in this balance I think the value of their work can be maximized.

At this point I would like to recall Dr. Foster's contribution in his discussion of the agrément situation, because the agrément system really is a recognition that you cannot state things fully at some given moment, and yet you have to get on and you don't want to leave big omissions; so you cover them by probabilities, by statements of what is believed rather than what is known.

Mr. Achenbach came out in one or two of his remarks about the difficulty and the cost of field work. I was able to make one or two suggestions about this, and the Division of Building Research is developing its field work vigorously. The fact is that one cannot sit in a laboratory and do a fully realistic job in this area of research. It is necessary to work in the field. A great deal of experience, a great deal of knowledge in the form of experience, is wrapped up in industry and in the work of the building professions, and only direct contact with the face of the work will make it a research resource. It perhaps seems expensive, but really only in the sense that it is unfamiliar. It is no part of our traditional idea of the costs of research in building. One is expected to pay $25, $50, or $80,000 for an electron microscope. It is less familiar to spend the same sort of money on a mobile laboratory. It's even regarded as almost a waste of time to go somewhere and just contemplate a thing, or to talk to people or to use sample surveying techniques for technological purposes. So I believe, as I know Mr. Achenbach does, that this kind of work simply has to be done. This is the market research of the building industry.

Dr. Wright talked about another aspect of measurement when he talked about the subjective and objective. People often despise—some scientists especially despise—subjective measurements simply because they aren't objective.

When we are measuring objects, objectivity is dead right. When we are studying people, we are *ipso facto* studying things subjectively. We are studying what goes on in the mind, in the sensory system. We are studying other things about people—behavioral habits, desires—often suppressed or unknown desires. If you haven't experienced something, perhaps you don't know what an asset it could be in your life. Subjective measurements which are so frequently derided are likely in building to be part of the ultimate reality. The criteria of good musical acoustics are musical; they are subjective and it is hard to make them objective. They are not of the objective nature of things, and call for a different kind of appraisal, characterized by probability. But probability is no disgrace in science. It is in fact one of the fundamental concepts of science; and when we are involved with people, we are involved with subjectivity.

We talk about things like houses, and households, but man and his shelter is our subject; and even with a careful choice of words I'm in danger of circumscribing the view that we ought to take.

The home and its environment. We think of a house, we think of a highrise building with an apartment in it, we think of homes for people. People often haven't homes. They must have homes and we say they must have respectable homes, and we think of respectable homes as being the right kind of stove, the right kind of heating system, the right kind of thermal insulation, the right kind of space. We relate this largely to comfort and to status symbols.

Man cannot live by bread alone, but by the grace of God. A technically good house is one thing, but its environment is another, and it is easy enough to see in many, many parts of the world—not least perhaps in some of your own great cities—that a roof over one's head is not enough. One can do bad housing with good houses; one sees it done often enough. But people will frequently think affectionately of their environment as good housing if they are happy in it, even if the houses themselves have shortcomings. It is largely the environment in which a home is set that makes it a success or failure.

This came through in several of the things that Mr. Bush said this morning and it was implicit in things that we heard about Columbia New Town.

There was a reference to Ebenezer Howard. I live in Welwyn Garden City, the second new town that he founded, and I know something of what he believed about environment, because I live in the result of it. I know that a great many of the houses are second-rate by good technical standards but I know that the environment is first-rate and that this makes it a place worth living in. I notice that people would rather not move from their second-rate houses, they would rather up-grade them and stay, because of the environment. The street in which they live, the street into which it leads, the whole neighborhood has a pleasure about it that lifts the human spirit. This is important, not to be neglected when we think of all those things which we can measure easily and accurately. I know a place in Britain where at the moment they are dismantling a hundred acres of post-war housing. It was put up in the supposition that a roof over peoples' heads was more-or-less all that mattered; the community buildings would have to wait, all those things which represented the graces and pleasures of life would just have to wait until "necessities" had been satisfied. Well the place became unpoliceable, the social costs fantastic; you leave a house vacant and

before you can say Henry Robinson half of it is taken apart. The whole area is in decay and nobody knows quite what is wrong and what to do about it.

I think it came out in some of the discussions of Columbia this morning. Can one afford underground utilities? I'm Canadian born; forgive me then if I come back to this side of the Atlantic for a moment, to recall memories of every Canadian town, not to mention some in the USA, with a forest of telegraph poles and wires. Can we afford underground utilities? Do we have to go on wrecking the environment with this wire-scape? It's one of the things I've had to admire in my adopted country that practically nothing of that sort ever comes above ground. Somehow or other, they have managed to afford it.

Mr. Mitchell gave us an exhilarating, breathtaking sort of display. It was both a case-history and a model, as I thought, of one of the roles of the Bureau. We had, in fact, a dual performance from Mitchell and Dr. Pfrang; and in the two we have a capsulated version of just what this conference was all about. The creation of a system which was an innovation. The necessity to create something which was adaptable, amendable to peoples' own needs; even to their participation, and the growth problems of their homes. A lot of human sympathy was written into the ideas.

The innovation confronted the Bureau and HUD with a problem, and I thought the discussion of how it was tackled was fascinating. But the operation that Mr. Bush described this morning, in which my friend Mr. Ehrenkrantz has been involved, is of course much the same kind of thing, though on a somewhat larger scale. I think one recognizes in Dr. Walton's assembly of the conference subjects much skill in picturing the nature of performance specifications alongside that of the problem through these imaginative and dramatic episodes in your national development. They are part of the whole family of ideas with which we are concerned here in this room, and I am sure that everyone can see the relevance of these examples to their own part in the total picture.

So I came to my conclusion. Most of you know the Bureau better than I do, but I am sure you will agree that we have seen it playing a new role in our industry.

Scientific organizations seldom seek leadership, but research by its nature moves its participants out in front, where a sense of direction is rather a necessity. I doubt if the organizers of this Conference had any leadership aspirations, but I think we are all aware that in putting it together they have somehow enabled us to discover the line of forward movement which is now developing, and to appreciate the Division's role in making it visible, helping it on, and monitoring it.

Not that I am overlooking the part played by HUD and other government agencies, but there is no time for me to examine the pattern of their interaction in these matters, nor am I in any way competent to comment upon it.

So, sir, I think that this has been a highly successful meeting. There have been excellent papers and I and others have learned a great deal. It has been excellent in every way. And since I am the last speaker, to you Dr. Walton as the senior chairman and organizer let me say on behalf of everybody here that we are all greatly indebted to you. To you therefore, and to Dr. Wright and to the Bureau, and in retrospect to Mr. Eberhard go our thanks and appreciation.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1969 OL—332-247